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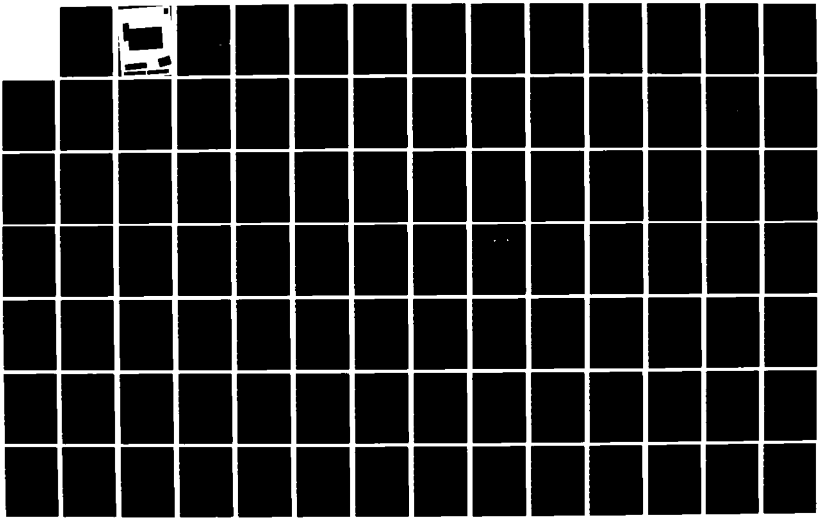

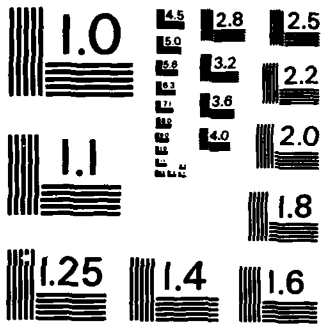

MICROCOPY RESOLUTION TEST CHART

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DEPARTMENT OF OCEAN ENGINEERING

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CAMBRIDGE, MASSACHUSETTS 02139

ULTRASONIC MEASUREMENT OF PARTICLES
IN A VISCOUS FLUID

by

LAWRENCE EUGENE OSLUND
LCDR USN

COURSE 13A

S.M.(NAME) February '85

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LAWRENCE EUGENE OSLUND

B.S., COLUMBIA UNIVERSITY, NEW YORK CITY
1975

Submitted to the Department of
Ocean Engineering
in Partial Fulfillment of the
Requirements of the Degrees of

MASTER OF SCIENCE IN

NAVAL ARCHITECTURE AND MARINE ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

4 September 1984

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Department of Ocean Engineering, 4 September 1984

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Accepted by: ______________________
Chairman, Ocean Engineering Department Committee

Accepted by: ______________________
Chairman, Mechanical Engineering Department Committee

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and

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

ABSTRACT

A fluid model has been designed and built to simplify the more complex study of particle dispersion in polymer melts. Focussed ultrasound is employed for maximum acoustic intensity within the focal zone for high resolution of particles between the diameter ranges of 100 - 10 microns. The theory of focussed radiators is discussed with emphasis on obtaining a minimum focal zone and beam width. The parameters necessary for particle detection in a viscous fluid are highlighted.

A signal processing system has been designed and implemented to allow quick, accurate, and reliable data acquisition with speeds up to 10 KHz. Incorporated in this system ~~are~~ the use is of state-of-the-art peak detectors which gate, digitize and store, for computer pick-up, the largest signal within the gated zone.

Preliminary tests have shown that glass spheres between the range of 15 - 10 microns are detectable in silicone oil. Results of these tests have been plotted, as well as, results from particles in the ranges of: 25 - 15, 35 - 25 micron glass beads and 32 micron polystyrene beads. (These)
A

Thesis Supervisor: Dr. Lewis Erwin
Title: Associate Professor of Mechanical Engineering

Thesis Reader: Dr. Koichi Masubuchi
Title: Professor of Ocean Engineering

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The financial support for my thesis was the result of two sponsors. As a commissioned U.S. Naval officer, I was given a two year window and tuition for full time studies in the Ocean Engineering Department, 13A program. Sponsoring the thesis topic and providing the funds for purchasing laboratory equipment was through the Industrial Polymer Processing Program under the auspices of Dr. Nam Suh, Professor of Mechanical Engineering. That program, a one of its kind for a decade, is funded by individual sponsors who have a combined interest for the basic research M.I.T. can provide. Of the dozen or so sustaining members of P^3, E.I. du Pont de Nemours, and in particular, Antonio Vidal, Fred Kafka and Stan Wilcox, were my constant source of contact and help for the duration of this research. But because of P^3 member and student unity, I extend my thanks to others who have been around to lend a hand and ear when need be.

As important as financial support, is the moral support of one's spouse. I thank my wife Loretta for that contribution.

Another special thanks goes to the gentlemen, Christopher Nemarich and Henry Whitesel, of David Taylor Naval Ship R&D Center in Annapolis, for their time, equipment support, and openness. Without their help I would be dataless.

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Last but not least are the M.I.T. undergraduates who helped with the dirty work although there was enough for all:

Ann Willerford who assisted in designing and building the laboratory model, ordering material and supplies, conducting independent tests, drawing the majority of my thesis figures and overall project collaborator.

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Barbara Conti for her time and conscience effort in proofreading this manuscript.

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LIST OF SYMBOLS

	Description, Units	*Page
a	RADIUS of the transducer radiator, m	26
c	Sound VELOCITY, m/s	22
c_1	Sound VELOCITY of focussing lens, m/s	26
c_2	Sound VELOCITY of fluid, m/s	26
e	DISTANCE between Transducer & Base, m	32
f	FREQUENCY, Hz (s^{-1})	22
t_{nm}	TIME between A_n and A_m, s	32
q	Transverse DISTANCE from Axis, m	28
x	Axial DISTANCE from transducer radiator, m	23
A	RADIUS of curvature, m	23
A_{lens}	RADIUS of curvature of lens, m	26
A_n	VOLTAGE Amplitude, V, (n=1,2)	32
B_w	Beam WIDTH, m	28
D	DIAMETER of the transducer radiator, m	22
D_i	DIAMETER of test particle, m, (i=1,2)	145
F	Focal DISTANCE, m	27
F_z	Focal ZONE, m	27
I	Acoustic INTENSITY, W/m^2	23
K_f	DEGREE of focussing	25
N	Natural focussing DISTANCE, m	21
P	PRESSURE amplitude, Pa (N/m^2)	26
P_{inj}	PARTICLES per injection	145
P_o	PRESSURE amplitude, Pa	26

LIST OF SYMBOLS (cont)

W_{pi}	WEIGHT of test particle, g, (i=1,2)	145
X_c	OUTPUT linear corrected value	54
X_n	OUTPUT non-linear raw value	54

<u>GREEK</u>:

λ	WAVELENGTH, m	22
ρ_i	DENSITY of test particle, g/cm^3, (i=1,2) .	145
ρ_f	DENSITY of test fluid, g/cm^3	145
α	ATTENUATION, Np/cm	31

* Indicates first page the symbol is used.

CHAPTER 1

INTRODUCTION

1.1 Research Purpose:

Through the Industrial Polymer Processing Program a question was posed: could an on-line measurement system determine how well a polymer has been mixed with a minor component containing solid fillers, such as carbon black? The question was later more generalized to include mixing a polymer with another polymer as the minor component. This challenge was addressed by the research of Dohner[1] with his results shown in Figure 1.1:

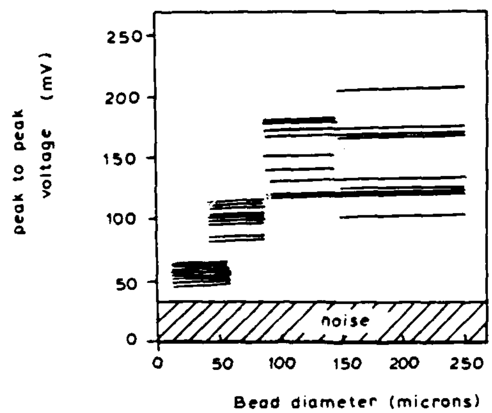

FIGURE 1.1 OUTPUT VOLTAGE VS PARTICLE SIZE RANGE

Increasing the diameter size of particles[1], used as the minor component, correspondingly increased the peak-to-peak output signal voltage of the detecting equipment. Although a calibration was not attempted, the feasibility of an on-line

$$K_f = \frac{F}{N} = \frac{4F\lambda}{D^2} = \frac{4Fc}{fD^2} \quad (2.7)$$

(for $\lambda \ll D$)

The degree of focussing criteria is arbitrary but the one considered useful in practice is that which Schlengermann[6] has proposed:

Weak Focus	$\frac{2}{3} < K_f \leq 1$
Medium Focus	$\frac{1}{3} < K_f \leq \frac{2}{3}$
Strong focus	$0 < K_f \leq \frac{1}{3}$

Our goal is to minimize the focal spot to achieve a high sensitivity: the transducer's ability to detect echos from small particles. The focal zone, F_z, (the length of the focal spot), is defined as the distance between points at which the pulse-echo amplitude drops to 50% of maximum amplitude (-6dB). The beam width, B_w, (the width of the focal spot), is the transverse distance (at a specified axial distance) between points at which the pulse-echo amplitude drops to 50% of maximum amplitude (-6dB). Figure 2.4 clarifies the dimensions.

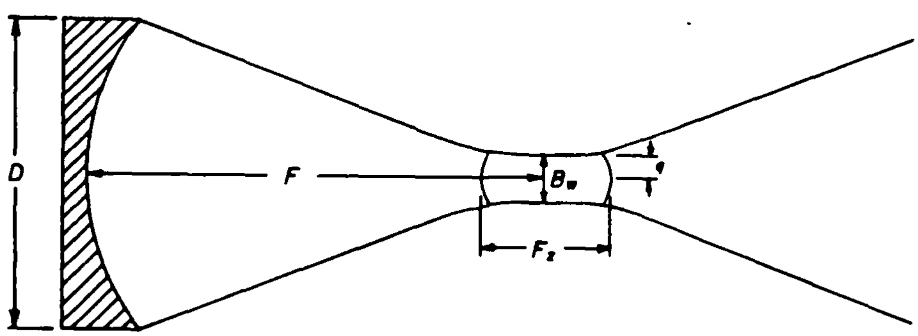

FIGURE 2.4 FOCAL ZONE AND BEAM WIDTH DIMENSIONS

focussed transducer. It should be noticed that the maximum acoustic intensity for A $= \infty$ is at the natural focussing distance of N as expected.

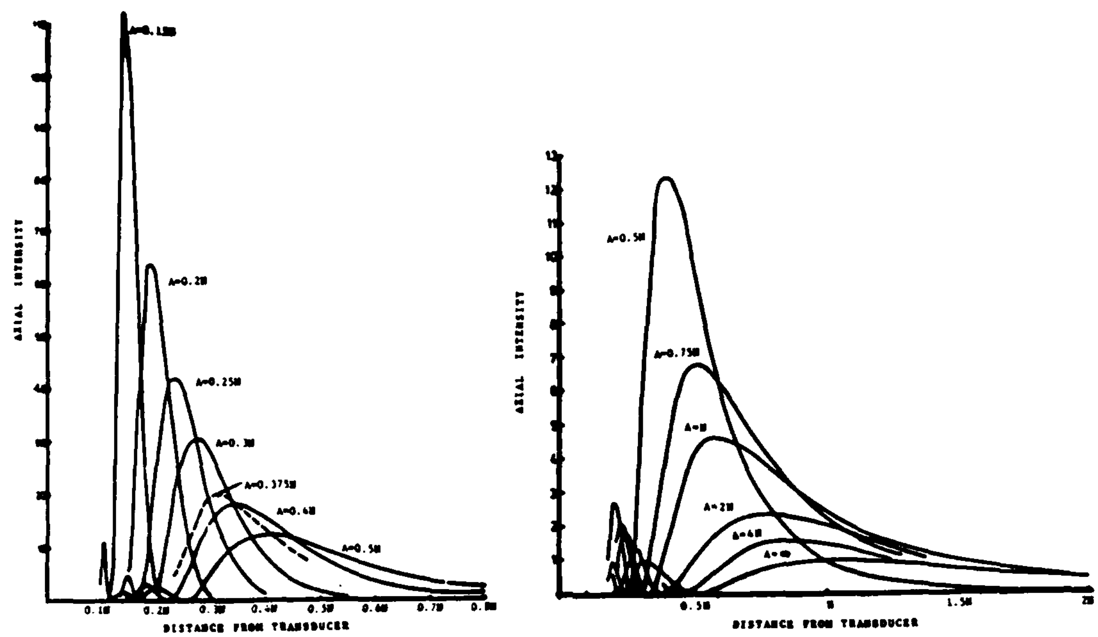

FIGURE 2.3 AXIAL INTENSITY OF A FOCUSSED TRANSDUCER[3]

In summary, focussed sound supplies greater target (particle) power density which provides a stronger reflection for the receiving transducer. Hence, a greater resolution is achieved without the necessity for compromise in the transducer diameter or frequency.

Its advantagous to define the "degree of focus", K_f, (or focussing factor) as the ratio of actual focal distance, F, to the natural focussing distance, N, (from Equation (2.2)):

further demonstrate the need for focussed sound is depicted in G. Kossoff's analysis of spherically focussed transducers[3] and is presented later in Figure 2.3. The axial acoustic intensity, I, is defined as: [4,5]

$$I = \{K \operatorname{Sin}[\frac{\pi D^2}{8 \lambda Kx}]\}^2 \tag{2.4}$$

with $K = \dfrac{A}{A - x}$

where:

A = Radius of curvature, m

x = Axial distance from transducer's radiating surface, m

What Kossoff calls the transition distance is also the natural *focussing distance defined earlier as N*, i.e., the demarcation between the near-field and far-field. Using the definition of N, (Eq 2.2), the axial intensity becomes:

$$I = \{K \operatorname{Sin}[\frac{\pi N}{2Kx}]\}^2 \tag{2.5}$$

In the case when the radius of curvature A is equal to the axial distance x (at the optical focus), the acoustic intensity reduces to:

$$I = \{\frac{\pi N}{2A}\}^2 \tag{2.6}$$

The curves show several strengths of focussing from $A = \infty$ to $A = 0.15N$ with $A = \infty$ describing a conventional, non-

where:

$$\lambda = \frac{c}{f} = 1100/5(10)^6 \text{ m/s} \qquad (2.3)$$

$$= 0.220 \text{ mm, wave length}$$

D = Transducer diameter, mm

c = Fluid sound speed, m/s

f = Transducer frequency, Hz

This indicates the near-field extends 183 mm while distance to the interrogation zone (illustrated Figure 1.2) is 13 mm. Therefore, if a non-focussed transducer is used, the tradeoff would be either in the radiator's diameter or in the radiator's frequency or a combination of both as illustrated in Figure 2.2 to ensure operation is in the far-field.

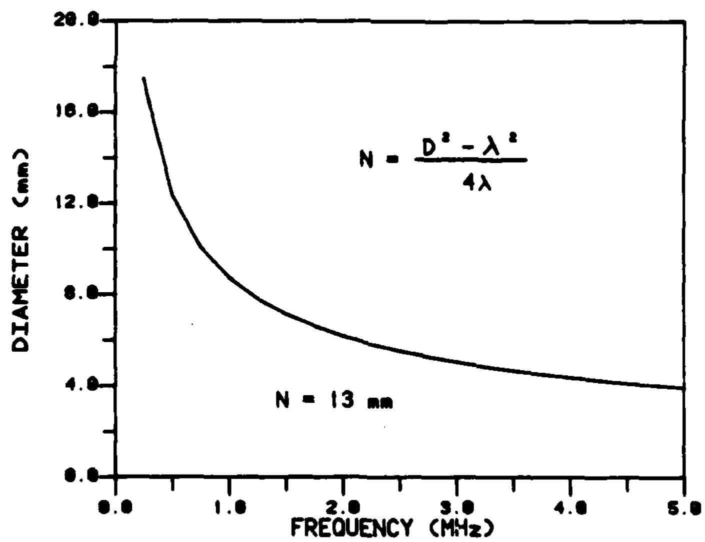

FIGURE 2.2 NATURAL FOCUSSING TRADEOFF

However, it is not sufficient just to have a 13 mm focal distance if the intensity of the acoustic beam is inadequate for particle reflections to be detected. Therefore, to

maximas and minimas. At the radiator's centermost section there may be a zero sound pressure but could, as well, have a pressure twice the mean if $\frac{D}{\lambda}$ is odd-valued. In either case, it should be noted that operating in the near-field will cause erratic results. Therefore, using a focussed

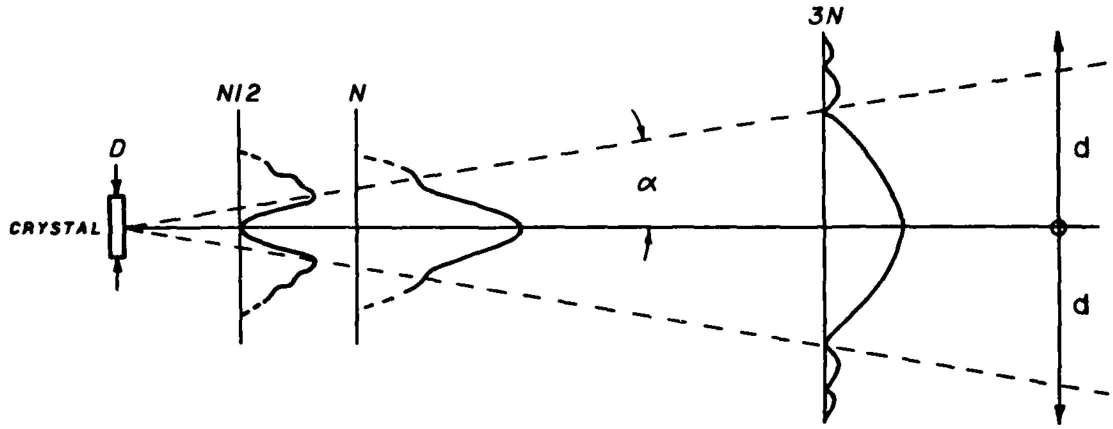

FIGURE 2.1 TRANSDUCER SOUND FIELD

transducer keeps the near-field effects out of the interrogation zone and the use of a "spike" pulsed transducer reduces the multiple maxima in the near-field[2]. (Spike refers to the speed, or short rise time, of the input voltage to the transducer).

For non-focussed transducers, Equation (2.1) is used to evaluate the natural focal distance, N:

$$N = \frac{D^2 - \lambda^2}{4\lambda} \tag{2.1}$$

$$N = \frac{(12.7)^2 - (0.220)^2}{4(0.220)} = 183.2 \text{ mm}$$

or

$$N = \frac{D^2}{4\lambda} \quad (\text{for } \lambda << D) \tag{2.2}$$

whereas absorption is sound energy converted into non-reversible heat transfer. Absorption is the damper of oscillation with greatest losses at the higher frequencies. Both losses set limits to the way testing is done. Pure absorption weakens the transmitted energy to and from the interrogation zone which can be remedied by increasing the pulser's output power, increasing the amplification (gain), or using a radiator with a lower center frequency. The remedy for scattering is only to use a radiator with a lower center frequency.

2.3 Details

2.3.1 Focussed Radiators:

At the onset of this research, the goal was to achieve a high resolution such that a particle in the range of 100 - 10 micron diameter could be detected. Focussed ultrasound was used to achieve this for the following reasons:

* Increase the sound intensity (power density) at the interrogation zone for an increase of the reflected sound pressure amplitude.

* Decrease the focal length (and near-field distance) and use the far-field range for predictable results.

Figure 2.1 is a typical sound pattern for a continous or long pulsed, non-focussed, plane wave transducer. The region nearest the face of the transducer produces a total of $2\frac{D}{\lambda}$

Transducer characterization tests physically compared several transducers in the pulse-echo mode by their ability to see micron – sized glass needles.

Transducer testing at elevated temperatures is a preliminary effort for future work (at 180°C to 300°C) with polymer melts. The acoustic delay line, used in previous work[1], and its concomitant energy losses is eliminated while testing on the model; the transducer lens is in contact with the model's fluid. The question asked: could a high temperature transducer be built to operate with its lens in contact with the polymer melt such that an acoustic delay line would not be necessary?

2.2 Summary:

Using a non-focussed transducer requires tradeoffs between the radiator's diameter and its center frequency for optimizing the focal distance of maximum acoustic intensity and beam narrowing. However, the reflections from micron size particles will still be insufficient to overcome the system noise. Therefore, spherically focussed radiators are used to increase the intensity at the interrogation zone one to two orders of magnitude greater than that of an equivalent non-focussed radiator.

Attenuation results primarily from two sources: scattering and absorption. Scattering is the result of inhomogenuities

CHAPTER 2

ULTRASONICS

2.1 Introduction:

Ultrasound is defined, generally, as a mechanical wave oscillating at frequencies above the upper limits of human hearing. The region of these efforts have been with center frequencies at 2.25 and 5 Megahertz (10^6 Hz).

This chapter combines theoretical studies with laboratory experiments. The theoretical work examines the need for focussed sound and investigates the controlling parameters for minimizing the beam width and focal zone, ie., the interrogation zone. While the focussing effect strengthens the reflection from micron size particles in the interrogation zone, attenuation decreases the strengths of both the incident sound wave and the reflective wave.

There are three laboratory experiments discussed:

* Attenuation and Sound Velocity Measurements
* Transducer Characterization
* Transducer Testing at Elevated Temperatures

Attenuation and velocity tests were run to pick a fluid for the model (discussed in Chapter 3) which best represents those properties in a polymeric melt.

review is desired, the DETAILS section should prove adequate. This should provide the reader with an opportunity to grasp an overview of the subject without becoming entangled in the details. There are six chapters which follow a logical progression of my research. Chapter 1, and 6 are of typical thesis architecture which provide the Introduction and Conclusion. Chapter 2 picks up the subject of Ultrasonics which ties previous work with additional theory for the specific research now being conducted. Ultrasonics is a lengthy topic in itself and therefore it has not been the author's attempt to teach class. However, sufficient information is provided in the DETAILS section to allow a continous flow.

Chapter 3 sets the stage for modeling the polymer extruder. The author learned of a similar model being used by the Navy Research and Development Center in Annapolis, Maryland during this time.

Chapter 4 introduces the Signal Processing scheme and the electronic equipment used for the data gathering.

Chapter 5 discusses the results from the testing.

[1] The word particle is taken synonymously with agglomeration of several small particles which is equal to the effective diameter of a spherical particle.

1.4 Thesis Objectives:

The <u>major objectives</u> of this research are to:

* Develop a non-destructive on-line system capable of detecting particles of a minor component in a viscous fluid.

* Plot a distribution of particle sizes with their respective concentrations.

Several milestone goals must be met for this to occur. These include the following:

* Verify the results from previous efforts.

* Determine the necessary parameters to enable particle detection.

* Model the polymer extruder to simplify several variables.

* Design a signal processing system to enable accurate, quick, and reliable data gathering and processing.

* Return to the polymer extruder and apply knowledge gained from the model.

1.5 Thesis Organization:

This thesis has been written for the convenience of the reader. Each chapter except the first provides an INTRODUCTION and SUMMARY of the results. If a more detailed

quality control. Mixing perturbations could be easily detected, classified, and system restored in minimum of time and material waste.

* Hydraulic and lubricating oil analysis is accomplished routinely as a measure of preventive maintenance or on a case basis when hydraulic repairs have been made. The analysis is a rather complicated procedure: measuring the chemical composition and pH, the amount, size, shape and composition of particles within. Again, the process is expensive and time consuming. Shown on Table 1.2 are the Navy's inspection standards for particle contamination on a submarine during overhaul and then when it's operational. During overhaul, a portable on-line monitor could be set up until particle count is within the required limits before calling the oil analysis lab for certification.

TABLE 1.2 LIMITS OF HYDRAULIC SYSTEM CLEANLINESS

SUBMARINE SHIPBOARD MACHINERY MONITORING				
PARTICLE DIAMETER (MICRON)	INTERNAL		EXTERNAL	
	OVERHAUL	OPERATIONAL	OVERHAUL	OPERATIONAL
15- 25	*22,800	---	45,600	---
25- 50	2,025	4,050	4,050	8,100
50-100	360	720	720	1,440
>100	64	128	128	256

* particles/100 ml fluid

TABLE 1.1 ALTERNATIVE MEANS OF INTERROGATION (Cont)

MECHANICAL:	ADVANTAGES	DISADVANTAGES
Filtration	Pore Size	Particles Deformed
Particle Bombardment (Electron Microscope)	Micron Focus	Requires a Thin Flow Stream
Elastic Perturbations:		
Acoustic Emissions	Continous	Small Signal
Ultrasonics	All	Temperature

1.3 Current Methods of Particle Detection:

Two methods are discussed: the quality of mix between the polymer melt components and measuring the level of contamination in hydraulic or lubrication fluid systems in use by the U.S. Navy.

* There are several means of measuring the "goodness of mix" between the polymer and its minor component, but one commonly used is with the scanning electron microscope. The primary characteristic of this and many other methods is the amount of time before results are known and the subjectivity of the tests. The preparation and quantifying operation is costly and, consequently, large amounts of material are not sampled. Therefore an on-line monitoring system could aid the engineer in determining the quality of mix for a new screw geometry or provide the production line with a verification of continuing

1.2 Conceptual Design:

The primary concept for an on-line measurement system consists of a "black-box" monitor located at the output end of a polymer extruder or on the prefilter side of a hydraulic or lubrication system as shown in Figure 1.2. Measurements of necessary parameters, with near real-time data output, are desired to have adequate and timely description of particles. The alternatives analyzed by previous efforts and discussed in recent thesis work[1] are provided in Table 1.1. The conclusion was the use of ultrasonics as being more advantageous for its versatility for detecting a greater number of mixtures, and was less costly than other systems with restricted capability. Other methods that were analyzed and rejected required a reduced flow rate, obstructed the flow, or were unreliable due to abrasion leading to high wear rates.

TABLE 1.1 ALTERNATIVE MEANS OF INTERROGATION

ELECTROMAGNETIC:	ADVANTAGES	DISADVANTAGES
Impedance:		
Unmodified	Non-Destructive	Wide Zone
Modified	Micron Size Zone	Flow Restricted
Dielectric Breakdown	--	Destructive
Wave Scatter (LASER)	All	Absorption Cost

system was shown quite clearly.

Concurrently, a similar task was being researched by the U.S. Navy: Can an on-line measurement system determine the size, shape, composition, and concentration of contaminants in an operational hydraulic or lubrication system? Two applications have been under consideration in this thesis:

* On-line determination of particle size and concentration for a laminar flowing, highly viscous polymeric fluid such as one would have with a melted plastic.

* On-line particle identification and classification in a laminar (or turbulent) flowing viscous fluid such as a hydraulic oil.

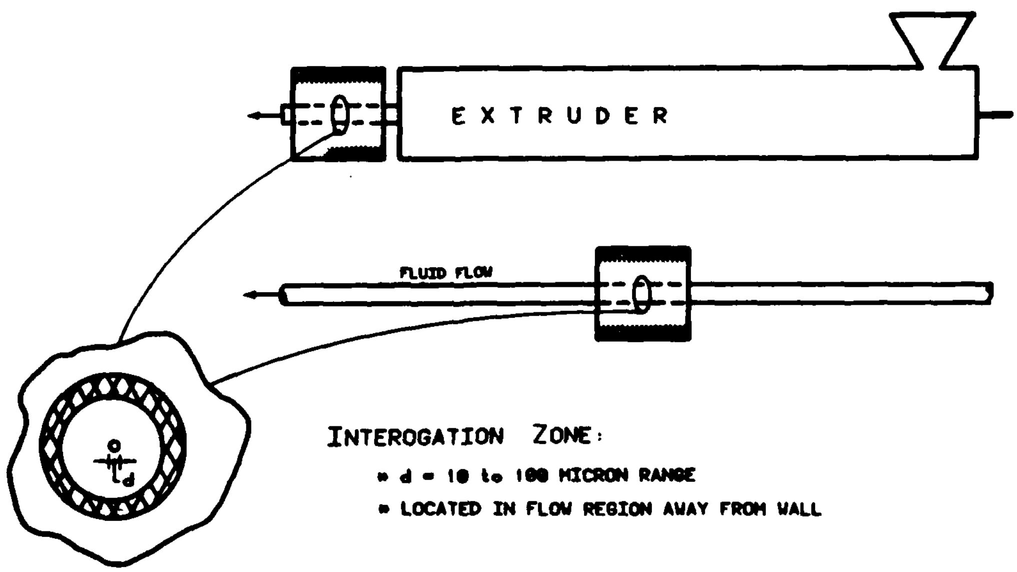

FIGURE 1.2 CONCEPT DESIGN

Calculating the focal zone, F_z, depends on how the transducer is mechanically focussed. One method employs an epoxy or plastic spherical refracting lens adhered to a plane radiator transducer while the other method uses a radiator which is spherically focussed. The first case requires an adjustment for differences of sound velocity, C, between the lens material and the adjacent medium (fluid). Equation (2.8)[2] provides the mechanism, with a rather lengthy computational approach if only the focal zone is needed, but facilitates either version of focussing and provides relative sound pressure along the axis. The focal distance, F, can be obtained by inspection off the example plotted on Figure 2.5.

$$P = P_o \left| \frac{2}{1 - \frac{x}{A}} \right| \left| \mathrm{SIN}\left[\frac{\pi}{\lambda}\left\{\sqrt{(x-h)^2 + a^2} - x\right\}\right] \right| \qquad (2.8)$$

$$\text{with} \quad h = A - \sqrt{A^2 - a^2}$$

$$\text{First Case:} \quad A = \frac{A_{lens}}{1 - C}, \qquad C = \frac{c_2}{c_1}$$

where:

A = Radius of curvature of radiator, m

A_{lens} = Radius of curvature of lens, m

x = Axial distance from transducer's radiating surface, m

a = Radius of radiator, m

c_1 = Sound velocity-lens, m/s

c_2 = Sound velocity-fluid, m/s

P_o = Pressure, (for calc = 1), Pa

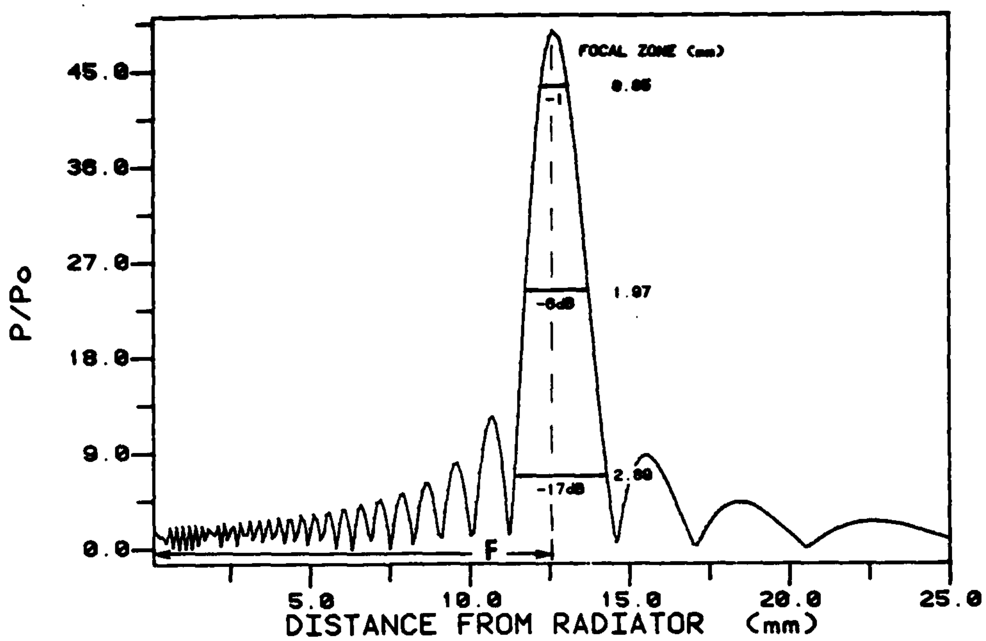

FIGURE 2.5 COMPUTATION OF THE FOCAL ZONE

A far simpler technique for determining the focal zone at the 50% pressure amplitude (-6dB) level is given by Wustenberg[7] in Equation (2.9) assuming the focal distance is known.

$$F_z = F\,K_f \left\{\frac{2}{1 - 0.5K_f}\right\} \quad \text{(at -6dB)} \qquad (2.9)$$

where:

F = Focal distance, m

K_f = Degree of focussing, (Eq 2.7)

Calculations for -1dB and -17dB zones are approximately 1/2 and 2 of the -6dB value[8].

Because of diffraction effects and spherical curvature, the point focus found in a geometrical sense is not possible[2],

and therefore, would like to know how narrow the beam width is. A method to evaluate the beam width, B_w, was developed by O'Neil[9] and was based on a similar approximation used in Rayleigh's solution for the directional pattern of radiation from a non-focussed plane wave transducer. The assumptions made, to ensure accuracy of solution, required the transverse di:tance, q, not be too far from the axis and in the vincinity of the focal spot. Equation (2.10) needs several iterations and the aid of a Bessel table to obtain q, therefore, Table 2.1 provides some of the more commonly used values.

$$F(z) = \frac{2}{z} J_1(z) \tag{2.10}$$

with $z = \frac{\pi}{\lambda} D \, \mathrm{SIN}\, \theta \simeq \frac{\pi D}{\lambda F} q$ (small θ)

$F(z) = P/P_o$, Pressure ratio

$B_w = 2q = \frac{B \lambda F}{D} = \frac{B}{4} K_f D, \quad B = \frac{2z}{\pi}$

where:

J_1 = Bessel function, first kind

z = Directivity function of a non-focussed, circular transducer radiator.

q = Transverse distance from acoustic axis, m

D = Diameter of radiator, m

F = Focal distance, m

λ = Wavelength, m

B_w = Beamwidth, m

K_f = Degree of Focussing

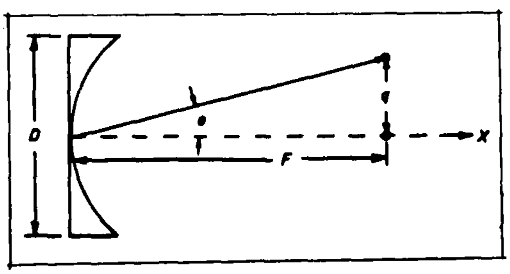

TABLE 2.1 COMMON VALUES FOR B_w COMPUTATION

P/P_o(dB)	F(z)	z	B
- 1	0.9441	0.6750	0.4297
- 6	0.7079	1.6140	1.0275
-17	0.3758	2.5615	1.6307
-20	0.3162	2.7315	1.7389

In summary, using focussed ultrasound has some distinct advantages for this particular application:

* No tradeoff on transducer diameter or frequency to accomodate the 13 mm focal distance.

* Maximize intensity by varying the degree of focus to enhance the transducer's ability to detect echos from small particles.

* Control the focal spot dimensions to within the constraints of the system.

Thus far we have worked forward, (given the characteristics of a particular transducer), calculating acoustic intensities and pressures, degree of focus, focal zone and beam width dimensions. But if a specific beam width is desired, could the process work easily in reverse? The equations and suggestions given below will support those efforts accompanied with some of the readers algebraic manipulation.

The following equation[7] eases the burden of figuring the radius of curvature from equation (2.8).

$$A \simeq N \left\{\frac{1}{1 - K_f}\right\} \{ K_f - 0.82\, K_f^2 + 0.43\, K_f^3 \} \qquad (2.11)$$

This will provide a good approximation for a spherically focussed transducer radiator especially where K_f is small. Another rule of thumb is that the maximum focus is achieved at $A = D/2$[Ref 6].

Table 2.2 is assembled to compare various parameters for non-focussed and focussed transducers with several conditions imposed.

TABLE 2.2 TRANSDUCER PARAMETER COMPARISON

	*D	*N	K_f	*F_z	*B_w	I	*A
NF	3.38	13	1.00	52.0	.87	1	∞
F	9.53	103	.13	3.5	.31	28	13.4
F	12.70	183	.07	1.9	.23	>110	13.2

* in mm

The following variables were constrained:

F = 13 mm
f = 5 MHz
c = 1100 m/s
P/P_o = -6 dB

with NF = Non-Focussed transducer
F = Focussed Radiator transducer

As a side note to focussing: Thus far the emphasis has been placed on sharpening the acoustic beam to nearly the diameter of the particles we are detecting. In non-destructive flaw detection, it is informative to know that the sound beam must be smaller than the flaws being inspected[10]. However, not all goals are achievable. In this case the dominating

influence is the attenuation of the sound by several processes in the polymer melt or the hydraulic fluid.

2.3.2 Acoustic Attenuation and Other Losses:

As friction in mechanical motion is ever present, the attenuation effect to a sonic wave is somewhat similar. But acoustic attenuation is a much broader concept accounting for many more causes than just acoustic energy transforming into heat. By definition, attenuation, α, is the summation of absorption and scattering as shown below.

$$\alpha = \alpha_a + \alpha_s \tag{2.12}$$

Further discussion on attenuation is referred to in [1,11].

2.4 Experimental Setup and Results

2.4.1 Attenuation and Sound Velocity Measurements:

A series of tests were conducted on several different fluids to support the initial design parameter of using a very viscous test fluid. The experiment was to find a fluid that had the right combination of sound attenuation and sound velocity that most closely represented a polymer.

In summary: The method used in these efforts was employed previously[1] during similar testing of polymer melts. The results indicated that using a silicone oil of a medium viscosity (200 centistoke (CSt)) would satisfy the design

requirements as well as keep the 35 micron and smaller glass spherical particles in semi-suspension. Other fluids were used before silicone oil because of ease of system cleaning. The sound speed of 500 CSt Dow Corning (200 Fluid) was 1050 m/s with and attenuation coefficient of 0.94 nepers/cm (or 8.2 dB/cm). The standard deviation was 8% of the average attenuation coefficient, however, most deviations exceeded 20%.

ARRANGEMENT: Voltage measurements, A_i, made between the diminishing peak amplitudes, determine the amount of attenuation in the medium. Time, t_{mn}, measured horizontally between any two adjacent peaks is the "time of flight"; time necessary for the sound to travel to the reflecting surface and back. Therefore, the velocity is simply determined by doubling the distance and dividing by the time. Attenuation is an exponential constant and requires the use of the natural logarithms for its calculation for units of Nepers/cm or the use of common logarithms for units in decibel (dB).

$$A/A_o = \exp(-\alpha x) \qquad (2.13)$$

$$\alpha = \frac{Ln}{x}\left(\frac{Ao}{A}\right) \quad Np/cm$$

where:

A = Maximum voltage, V

A_o = Minimum voltage, V

t_{nm} = Time between peaks n & m, s

$x = e$ = Distance, cm

1 Np = 8.686 dB

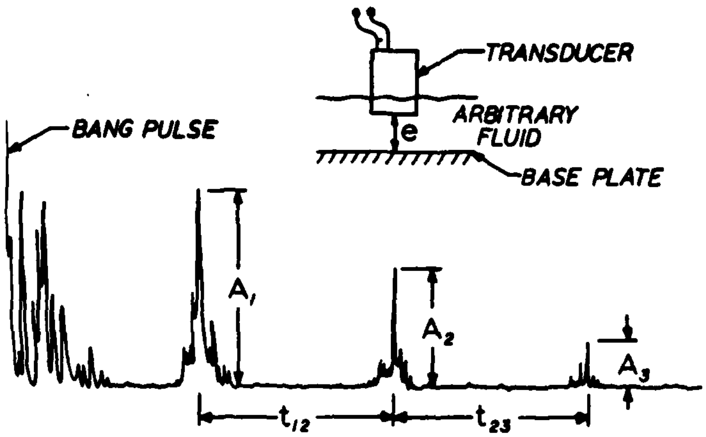

FIGURE 2.6 VELOCITY AND ATTENUATION MEASUREMENTS

RESULTS/CONCLUSIONS: Table 2.3 provides the calculated data for velocity and attenuation measurements:

TABLE 2.3 FLUID VELOCITY AND ATTENUATION

Fluid	Viscosity (CSt)	Velocity m/s	Attenuation Np/cm	dB/cm
Silicone oil	500	1050	.94	8.17
	10,000	1024	.82	7.11
	30,000	1033	.96	8.36
	60,000	1040	.93	8.09
Cutting Oil		1377	.22	1.91
Hydraulic Oil (5606)		1369	.13	1.11
Mineral Oil		1535	(not	avail)
PE Melt[1] (reference)		1500	.89	7.72

Velocity measurements seemed to progress without much difficulty but determining the attenuation coefficients proved somewhat arduous. The standard deviation in the results between points was quite significant leaving some doubt regarding the technique used. Further reference to

more sophisticated methods of determining attenuation can be found in [11].

2.4.2 Transducer Characterization:

The purpose of knowing the transducer's character is to:

* Determine the signal strength at the transducer's focal point by use of a small spherical reflector.

* Determine the -6 dB focal zone and -6 dB beam width.

* Determine the signal strengths by varying the reflector sizes.

ARRANGEMENT: The set up consists of an x-y table on a microscope base with a vertical positioner attached for the z axis. Affixed to the base is a fluid trough which holds the point reflector (glass needle) in place. The resolution of the x-y is one tenth mil (0.0001 inch = 2.54 microns) while the z plane is one mil (25.4 microns).

The needle is held horizontally in place in the movable trough and provides the x-y motion. The transducer is clamped to an adjustable vertical axis which functions as the z coordinate.

PROBLEMS ENCOUNTERED:

* The transducer alignment tends to be very time consuming and there is no means to ensure it is correct until the

trough is filled and operational.

* There is no means to accurately determine whether the transducer beam is symmetrical. This must be assumed that the manufacturer has checked and it is within the one degree nominal tolerance.

* The maximum length of the transducer + 150% of the focal length can not exceed three inches. To use longer lengths will necessitate lengthening the trough.

2.4.3 Transducer Testing at Elevated Temperatures:

A transducer was built to withstand high temperatures in preparation for contact testing with polymer melts. A hot oil bath was constructed and a temperature of 198°C was reached and held for six hours.

In summmary: The net sensitivity loss was less than 20dB and within the gain adjustment of the receiver-amplifier.
Later use of that transducer, in the polymer system, resulted in its demise. The manufacturer is currently evaluating the cause.

This experiment was designed to determine if:

* A transducer could be made to withstand 200°C polymer melt temperatures.

* What losses would be incurred while operating at 200°C.

Harisonic Labs[12] was requested to build a transducer capable of enduring a high temperature application. The design incorportated a plane wave "naturally" focussed, with an 8 mm active element, protected by a thickness of high temperature epoxy. The transducer's center frequency was at 5 MHz and approximate focal length of 13 mm.

ARRANGEMENT: The test consisted of an silicone oil bath that was heated, temperature regulated, and mixed by special equipment. The transducer was aligned for maximum signal reflection from a 3 x 4 inch aluminum block at a distance of 13 mm. The oil bath was heated in incremental steps of $5^{o}C$ past $100^{o}C$. Once at the desired temperature, the oil was allowed to stabilize for several minutes before taking data. Gain adjustments were made on the receiver-amplifier to maintain a constant signal amplitude, which is a standard method used to alleviate the possibility of non-linearities in the receiver. The gain was verified by sending a 5 mV, 5 MHz signal back through the receiver and measuring its ouput.

TABLE 2.4 TRANSDUCER HIGH TEMP TEST

TEMP (^{O}C)	GAIN (dB)
30	*7.6
90	8.9
100	10.6
110	12.9
120	15.0
130	15.8
140	17.1
150	17.1
160	18.2
170	19.2
180	24.2
198 (6 hours)	+ 9.8

* same 30-80^{O}C
\+ transducer moved

As shown on Table 2.4, the additional gain required was minimal up to 170^{O}C before increasing more rapidly. A severe loss of the return signal strength was expected because of previous testing done by Argonne National Labs[13]. The total loss was anticipated to be about 30 dB whereas actual loss was -17 dB.

PROBLEMS ENCOUNTERED: Several areas should be discussed to prevent the previous difficulties.

* The coaxial connector at the micro-dot connector on the transducer overheated and necessitated the probes's removal. Poor transducer damping was noticed after its rentry into the oil bath. (See (+) from Table 2.4). A high temperature cable must be used for future use.

* Temperature gradients in the oil caused erratic return

signals. This was corrected by repositioning the oil output nozzle.

RESULTS/CONCLUSIONS: It was found that after several hours of subjecting the transducer to high temperatures:

* Output loss could be reasonably corrected with an increase of system gain.

* The loss difference between adjacent temperature increments was negligible.

* Loss was minimal over the six hours of testing at 198°C.

CHAPTER 3

THE FLUID SYSTEM MODEL

3.1 Introduction:

A fluid system model was developed to simplify several parameters not easily regulated with the polymer extruder. The model consists of a positive displacement pump, 1.8 liter control volume piping loop with a particle injection port and mixer section, a filtration loop, and system pressurization equipment. Test particles of known size and concentration are injected and continously circulated in the control volume until sampling is complete. The fluid is then routed to the sub-micron filter for particle elimination.

An illustration of three key parameters easily monitored by the model are the following:

PARTICLE CONCENTRATION: An incremental amount of particles of known weight and size distribution are injected into the control volume and allowed to circulate and mix. When they become homogenously dispersed throughout the fluid, data is acquired by computer and stored on flexible disk for further analysis. This process is repeated several times until particle saturation. Saturation is defined as two or more particles sharing the ultrasonic interrogation zone (focal spot) at any particular time. Initial testing with a polymer-filler mix did not provide adequate precision. For

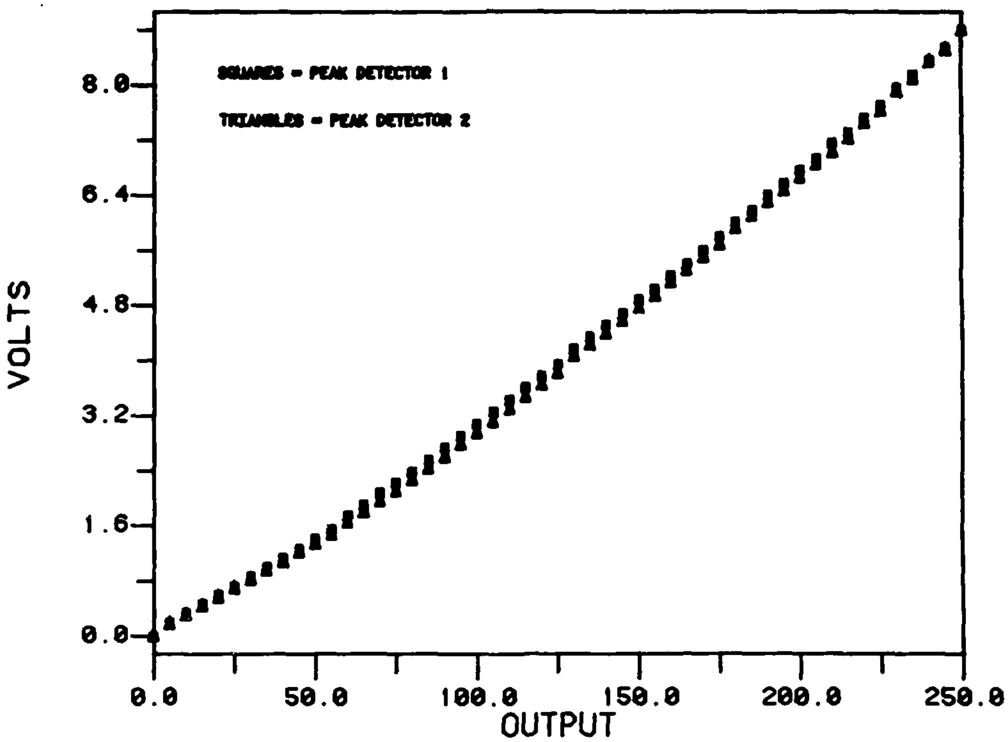

FIGURE 4.2 PEAK DETECTOR CHARACTERIZATION

With either method, knowing the raw ouput and the linear input data, the corrected output is then obtainable. A look-up table, for each channel, can be generated rather easily in which the raw ouput voltage becomes the array locator for the corrected value. This method is the fastest and most accurate.

The curve fitting method can be used where memory is a limitation, and can provide satisfactory accuracy to within the 8-bit resolution of the system. In this method, a polynomial function is found that best fits the non-linear curve, as shown in the previous figure. The method of least squares can be used with goodness of fit determined by chi-

4.3.2 HOW IT WORKS: A reflected mechanical sound wave is received and converted, by the piezoelectric transducer, to a small amplitude signal (1-10mV). This is sent to the receiver-amplifier which boosts the signal a 1000x (60 dB) to a range compatible with the peak detector. The peak detector gates the time region of interest and digitizes (to 8-bit resolution) the largest peak within the gated zone. The digitized output is then acquired and stored by the computer. Further reference to the electronic gating operation can be found in Dohner's thesis[1] and many additional references such as Krautkramer[2].

4.3.3 SYSTEM CALIBRATION (LINEARIZATION): The necessity of having a calibration is to offset or make corrections to the data because of system non-linearities. The characterization of the peak detectors were done with the results shown in Figure 4.2.

The non-linearity of the receiver-amplifiers was assumed to be negligible in comparison with the non-linearity of the peak detectors. This is not a bad assumption because of the broad band nature of their design.

Two methods for the computer to manipulate the raw data:

* Look-up Table
* Curve Fitting

the center flow in the test assembly. The output then digitizes the maximum amplitude from each particle's reflection within that region. The electronic gate is variable but was generally set for a two microsecond width. This gave a one millimeter reflection range which coincided with the focal spot of the transducer.

When the peak detectors complete digitizing, a "data ready" signal is sent back to the MINC—11 computer indicating the outputs are ready to be acquired. Using the MINC's internal memory (64K RAM) served as a quick input but provided limited room for the number of samples taken.

4.3 Details

4.3.1 ARRANGEMENT: The processing components consist of the transducer, receiver/amplifier, the peak detectors, and the computer as illustrated in Figure 4.1.

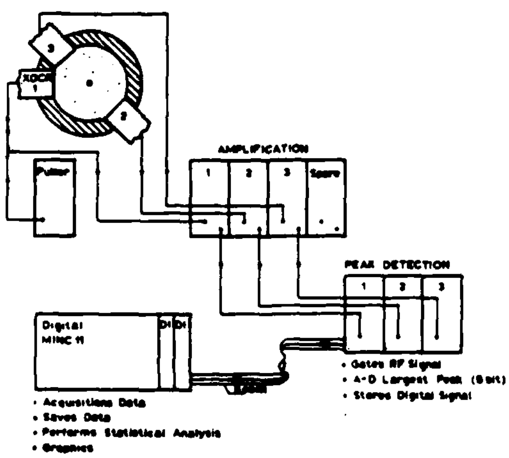

FIGURE 4.1 SIGNAL PROCESSING SCHEME

CHAPTER 4

ELECTRONICS AND SIGNAL PROCESSING

4.1 Introduction:

This chapter discusses the electrical and electronic process of particle detection. Two key elements are the ultrasonic transducer and the data collection system. The Piezoelectric transducer is electrically pulsed and caused to vibrate at frequencies about its center frequency. Before the next pulse, the sound wave has returned, transformed to a electrical signal, and collected as a data point.

The signal processing equipment receives this signal, amplifies, digitizes and stores it in the computer main memory until the sampling is complete. Then the data is stored on flexible disk for additional analysis.

Some peculiarities of the electronic equipment, and in particular the peak detector, is the non-linearity of their output. Two calibration schemes are introduced to determine and correct the non-linearity of the equipment.

4.2 Summary:

The electronic system design allows simultaneous inputs of a two or three transducer array. One peak detector per transducer is used to gate (window) particle reflections from

necessary correction. The problem was one millimeter or smaller diameter air bubbles were being formed in the pump when it was operating at 5 revolutions per minute (RPM) or faster. The initial assumption was that the test fluid was contaminated and so a change was made to the Dow Corning 200 Fluid. It was then noticed that the origin of the bubbles was coming from the pump's outlet. The question was still unresolved. The pump was disassembled several times but the cause of the air remained undeterminable. Only after considerable time and effort was the solution found: by pressurizing the entire model to a minimum of 14 PSIG the air bubbles disappeared.[14]

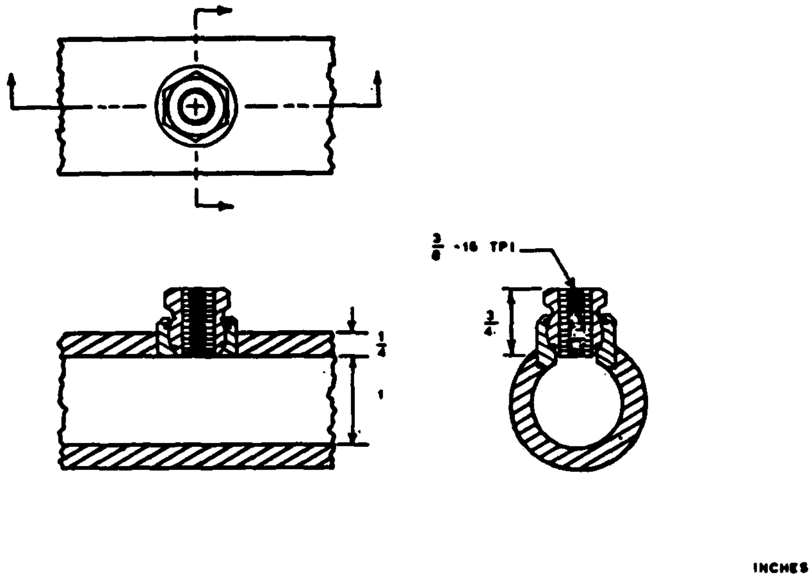

FIGURE 3.2 TRANSDUCER ALIGNMENT

Serious problems in the design and manufacture of the alignment ports persuaded other alternatives. If a mechanical adjustment could be accomplished without leakage, then the pulsing transducer should be the location of the effort.

It was also desired to observe acoustic scattering at 30° incremented angles about the one inch inside diameter (ID) test section. This was not done because the 9.5 mm transducer required a minimum of 45° for the ID mechanical clearance.

3.3.4 PROBLEMS ENCOUNTERED: Once the test section was manufactured and installed in the control volume, several difficulties were encountered. With the exception of one problem, all the others were resolved rather quickly. Several months were required to determine a noise source and effect the

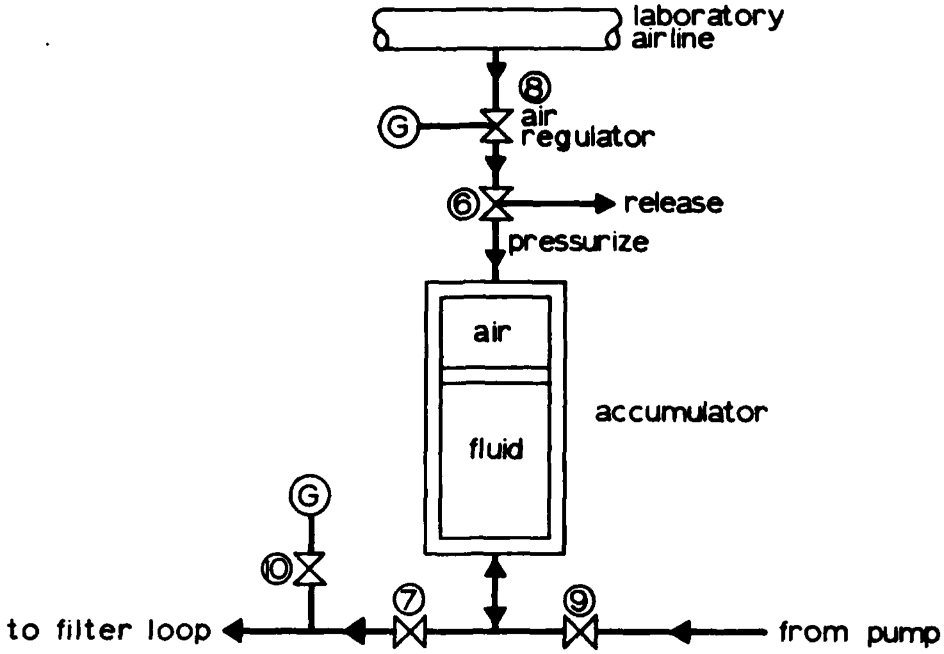

FIGURE 3.1 PIPE SYSTEM SCHEMATIC (Cont)

3.3.2 TRANSDUCER RADIAL POSITION/ALIGNMENT: One facet of this research incorporated the use of multiple transducers about a cross sectional plane. Since the acoustical axis may vary from the mechanical axis, the idea of "perfect" alignment with all transducers focal point at the center was considered.

A ball and socket joint, as shown below, was made with a retainer to prevent the ball from popping out and an O'ring at the ball seat to prevent leakage. Despite several machining efforts, fluid leakage did not cease.

that pressure be removed to prevent a possible ejection of the plunger from the syringe.

The kenix is a mixing section which provided the heating for the degassing operation in the reservoir loop section. Heating bands were wrapped around the kenix, and thermo-coupled to control the necessary temperature, for reducing the fluid's viscosity. It is no longer used in that capacity and only provides its secondary mission of mixing the particles as they circulate throughout the fluid.

The test section is manufactured out of aluminum and provides a secure mounting for the transducer(s). The test section is easily removed by union fittings, for cleaning, machining or renewal.

The PRESSURIZATION LOOP was the final addition to the fluid model to keep the dissolved air in solution and prevent its coalescence. It operates from a regulator off the laboratory air supply primarily for safety reasons than for convenience. (A gross error could only pressurize the loop to line pressure of 120 PSIG than to well over a 1000 PSIG had a nitrogen tank been used.)

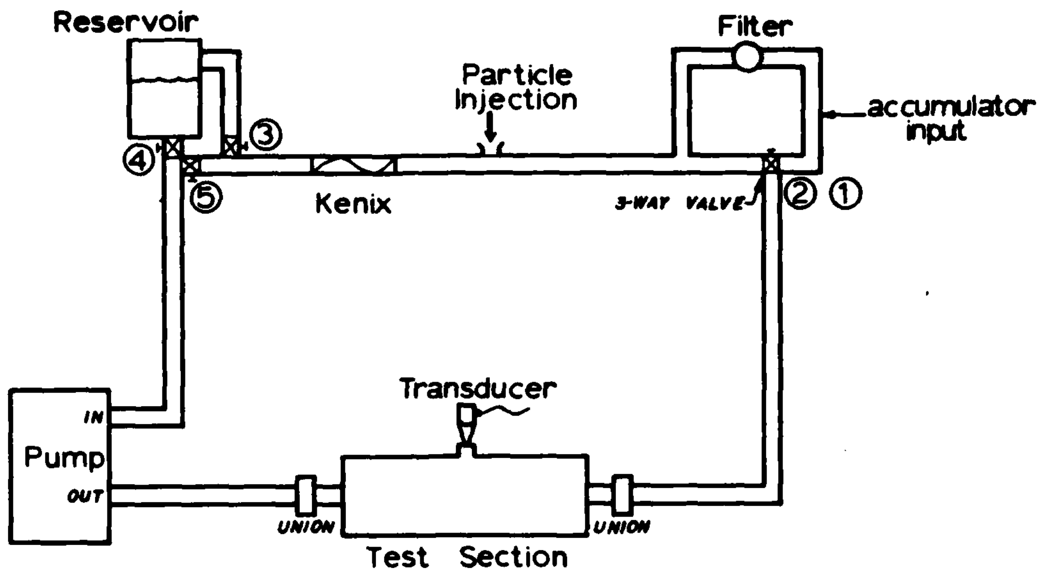

FIGURE 3.1 PIPE SYSTEM SCHEMATIC

remains in a closed volume during the testing mode. The construction is of one inch, schedule 40 clear PVC, and when properly joined, will withstand internal pressures up to 220 PSIG. Normal operating pressures should not exceed 30 PSIG with a minimum of 14 PSIG during slow speed operation. The particle injection port, kenix and the test section are three features of the control loop that will be discussed next.

The particle injection port consists of a 1cc syringe and needle and provides the means of injecting known qualtities of particles into the control volume. The syringe is removable while the needle is adhered and clamped in place to prevent leakage. Although this operation can be conducted while pressure is on the system it is strongly recommended

3.3.1 ARRANGEMENT: The fluid loop consists of four major sections that will be discussed below and illustrated in Figure 3.1:

* Reservoir Loop
* Filter Loop
* Control Volume Loop
* Pressurization Loop

The RESERVOIR LOOP is now defunct and serves only the purpose of filling the system. Its previous service was to provide a means of adopting a vacuum to the system for degassing the fluid after the viscosity was reduced. When that did not solve the problem, special flow channels were fitted within the reservoir to circulate and keep the air ridden fluid from entering the pump's suction. In this application the visible air bubbles were in fact trapped, however, micron size bubbles continued to evade the snare and coalesce within the pump cavity. When pressuring the system came about, the reservoir was discontinued from further use.

The FILTER LOOP was the means of eliminating the test particles from the fluid. It has a twenty inch .45 micron pleated filter cartridge and can filtrate fluid viscosities of 200 centistoke (CSt) at system's maximum flow rate. The fluid is routed either to the filter loop or bypassed away with a twist of a three-way valve.

The CONTROL VOLUME LOOP is called such because the fluid

once. Assuming an extremely viscous fluid would be flowing within, considerations were given to the performance of the pump and filter. These included ensuring the pump would not draw air from the shaft seal, and having the ability to keep an adequate flow rate through the sub-micron filter. Other qualities in the pump were the following:

* Positive displacement with rotational speed proportionally regulating the flow rate.

* Non-surging or pulsating.

* Able to pump abrasive fluids.

* Impart minimum energy to the fluid to eliminate cooling.

* Use of mechanical pump seals to minimize external leakage and loss of particles out of the control volume.

* Economical and stocked.

The elimination of air bubbles in the fluid dominated much of the effort of this research. Once the problem was corrected, through pressurizing the control loop, testing was able to proceed without further delay.

3.3 Details:

With the decision made to model the polymer system with a fluid system, there was a question as to which fluid would best represent the polymer. The first assumption was that the fluid must be very viscous. To verify this, a series of tests were conducted, on seven different fluids, to find the right combination of two parameters; the attenuation coefficient and sound velocity of the fluid should be within the ball-park of a melted polymer. This was considered important because:

* A false confidence could be incurred if all sized particles were measured. (negligible attenuation)

* Confidence in the ultrasonic method could be jeopardized if only the largest particles were seen. (significant attenuation)

* Sound speed would only affect the focal distance, F, of the transducer but is important since acoustic scattering is to be considered. Note: This applies only to transducers using a refracting lens for focussing.

The design process considered five major items: The piping network, a test section (on which the transducers would mount), pump, filter assembly, and a suitable transducer. Although many items depended on what the other looked like, decisions were made to keep many parallel efforts going at

an extruder would result in a cost of approximately $1000 per sampling (based on $42 per gram). Using a fluid model with the same particles would be less than $5 per sampling and the particles would continued to cycle within the control volume and additional sets of data could be taken.

TEMPERATURE: There are complications when a piezoelectric transducer is subjected to elevated temperatures. Careful selection of transducer materials will allow a unit to be subjected to the polymer melt temperatures but have found little success to date. However, this critical parameter was eliminated entirely through use of the fluid system operating at room temperatures.

3.2 Summary:

The fluid model was designed to overcome these basic issues while having the following characteristics:

* Known particle concentration.
* Known Particle distribution within a narrow range.
* Elimination of temperature effects.

A particle detection (calibration) system was intended to be used under laboratory conditions for gaining the most information with the minimum number of variables. The analysis and results of the model are to be applied to understanding the more complex polymer system.

example, polyethlene and carbon black (a tracer) were mechanically premixed and extruded at a volume rate to give a minimum throughput time of 45 seconds. While purging the extruder with clean polyethylene, various concentrations of carbon black continued to be output for the next hour. Therefore the known concentration at any particular time would only be an estimate. Thus, a fluid system was considered as a reasonable alternative especially when analyzing very small concentrations.

PARTICLE SIZE: Along with having a known concentration, it is important to have a known particle distribution within a relatively narrow diameter range. The spherical particle sizes listed in Table 3.1 were considered adequate.

TABLE 3.1 PARTICLE TEST SIZE AND RANGE

SIZE	RANGE
10- 15 Microns	5 Microns
15- 25 "	10 "
25- 35 "	10 "
35- 45 "	10 "
45- 75 "	30 "
75-105 "	30 "

Detection of 15-10 micron (0.4 mil) diameter particles was optimistic so the particle distribution was kept within a sufficiently narrow range to confirm accurate sizing and model calibration. Ranges were increased on the 105-15 micron size particles to span that gap and provide reasonable sizing and calibration. Using similar precision particles in

square[15]. It is likely that more than one polynomial along the curve will be necessary to obtain the best fit.

Once the functions are found, (ie., determine the polynomial coefficients), they are set equal to the linear equation in which the linear output is easily calculated. The difficult part will be obtaining the good curve fit. For the matter of clarity, a simple example is given below.

$$Y_1 = mX_c + b \tag{4.1}$$

where:

$m = 10/256 = 0.0391$, Slope

$b = 0.0195$, Intercept

$$Y_2 = C_1 X_n^{\,2} + C_2 X_n + C_3 \tag{4.2}$$

Shown in Figure 4.3, the Y's remain the same ($Y_1 = Y_2$) and only want to calculate X_c.

$$mX_c + b = C_1 X_n^{\,2} + C_2 X_n + C_3$$

$$X_c = \{C_1 X_n^{\,2} + C_2 X_n + C_3 - b\}/m \tag{4.3}$$

where:

C_i = Function coefficients

X_n = Non-linear output of peak detector.

X_c = Linear corrected output

Y_1 = Linear correction eqn.

Y_2 = Non-linear function describing the peak detector

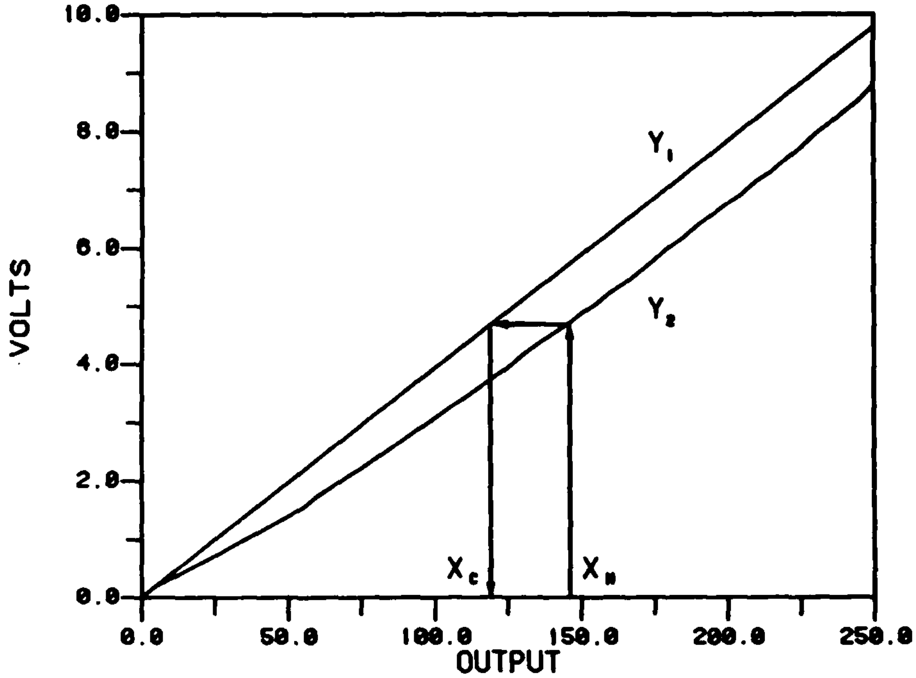

FIGURE 4.3 CORRECTING A NON-LINEAR OUTPUT

Data Acquisition: This is perhaps the time consuming part, but once the data is taken, it should not need redoing unless internal adjustments are made to the peak detectors. Two methods are available:

* Manual
* Computer Controlled

Manual Method: Figure 4.2 is the results of the manual data gathering method. How this method operates is shown by a block diagram in Figure 4.4 and discussed below. The function

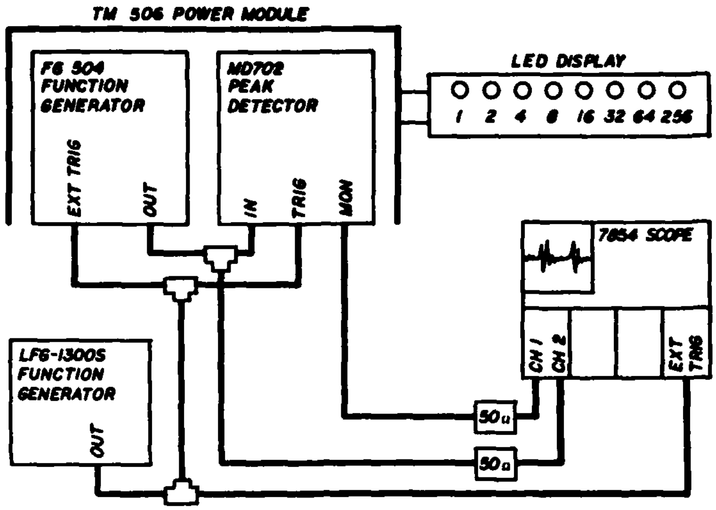

FIGURE 4.4 MANUAL CHARACTERIZATION

generator, FG 504, outputs a 5 MHz sine wave while synchronized by a second function generator with a 10 KHz variable width square wave. The result is a train of 5 MHz bursts with each burst separated by the sync repetition rate. Each burst is adjusted to 25 microseconds width with the gate extending past.

Five steps are required to set up and take a data point:

* Adjust the FREQUENCY of the FG 504 to that of the transducer's center frequency, and set the trigger to GATE.

* Adjust the second function generator to oscillate at 10 Hz and adjust the SYMMETRY function for a pulse width of 25 microseconds.

* Set the ATTENUATOR to -50dB (minimum voltage output) on

the FG 504 and adjust the VAR to 3.5 mV or until the first LED illuminates bright and steady.

* Record the peak voltage on the scope using the minimum VOLTAGE/DIVISION setting necessary to encompass the entire waveform.

* Increment the VAR until the next light is lit and repeat steps d. and e. until all 256 values are taken.

This method is long and tedious and is susceptible to frequent errors. The computer controlled method discussed next is superior, however, it has not been developed.

<u>Computer Controlled Method:</u> The block diagram in Figure 4.5 illustrates the proper flow. The CLOCK provides the input to the D/A, which in turn provides an analog output

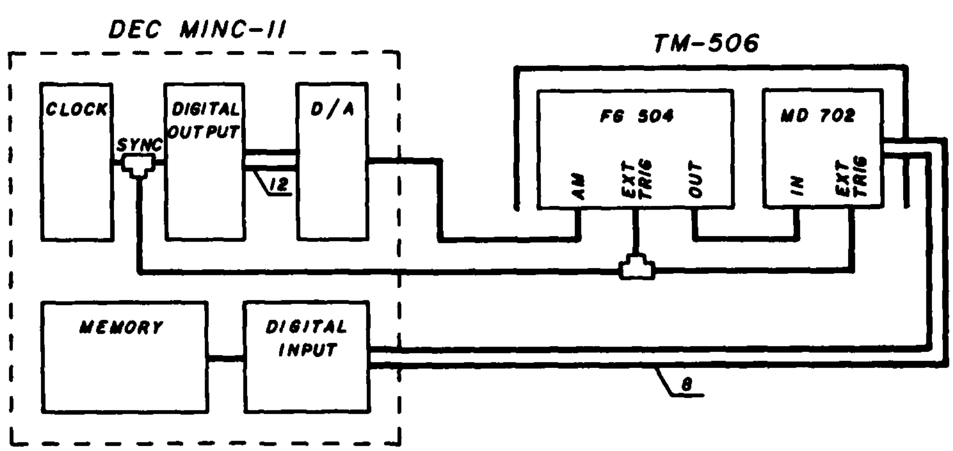

FIGURE 4.5 COMPUTER-CONTROLLED CHARACTERIZATION

to the AM INPUT of the FG 504. The AM (amplitude modulation) function increases the amplitude, which is similar to adjusting the VAR manually.

All of the above modules are available on the DIGITAL MINC-11 system and can be controlled as subroutines in a Fortran or Macro main program.

4.3.4 PROBLEMS ENCOUNTERED: (Manual Method)

* For reasons unknown, the method worked correctly while the peak detector's gate was less than the width of the burst.

* Adjusting the VAR on the FG 504 to keep the LED illuminated is sometimes difficult. Increase the ATTENUATION by one step and try again.

* To obtain small millivolt outputs without the usual internal noise may require the use of an external attenuator.

* Only a function generator with external gating can be used.

CHAPTER 5

EXPERIMENTAL RESULTS

This chapter reviews the data obtained from the fluid model using equipment and methods of signal processing.

Particles are injected into the control volume with a pre-established test sequence as shown in Figure 5.1. Each injection is assumed to contain an equal number of particles, and the particles are assumed to be thoroughly dispersed in the fluid before sampling. Data is acquired at a rate of 2000 points per second (per transducer) with a total quantity (per transducer) of 16,384. This sampling rate was adjusted to allow a particle passing through the interrogation zone to be strobed several times.

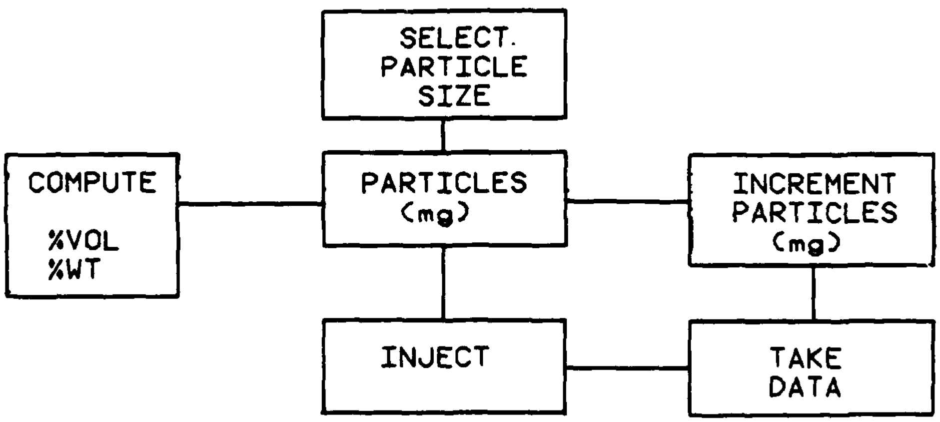

FIGURE 5.1 TEST SEQUENCE

Figure 5.2 shows an example of the peak detector's digitized output when a particle passes through the transducer's focal zone. The peak height is considered to be indicative of the particle 's diameter, and also the location of that particle within the interrogation zone. Two peak outputs illustrated below were found to be typical; a peak is reached either through several local max and mins or in a straight and narrow manner. As compared with previous results[1], the high frequency perturbations were eliminated by reducing the particle concentration and narrowing the interrogation zone. Therefore, the plots in Figure 5.2 are few and far between and easily recognizable. Additional results may be viewed in Appendix B where the first 256 of the 16,384 points are plotted.

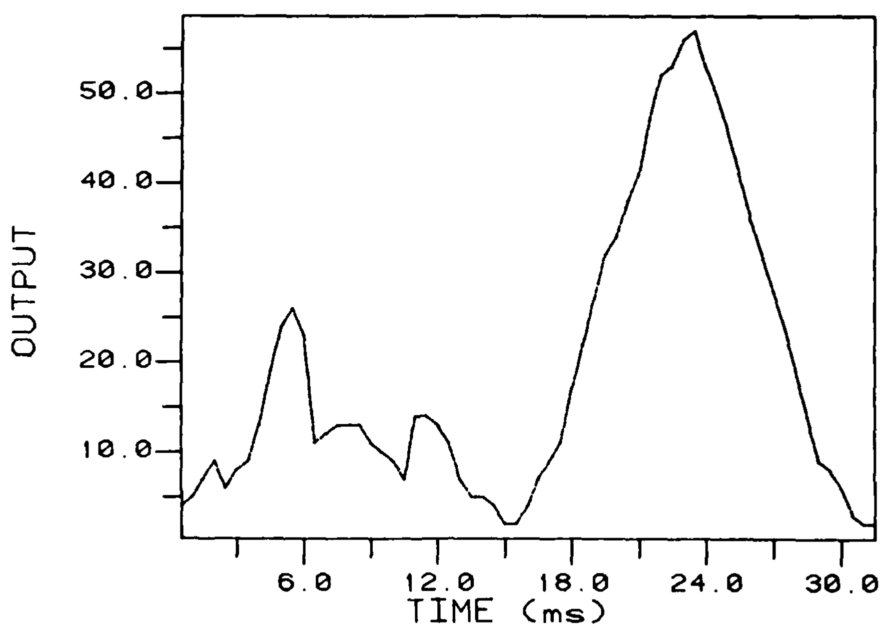

FIGURE 5.2 OUTPUT OF AN STROBED PARTICLE

The minimum detectable particle size were glass spheres in the 15-10 micron range. The density ratio between the glass spheres and the fluid was about two and one half times. For comparison, 32 micron polystyrene spheres with a density ratio near one were tested with equal success.

Presented in Table 5.1 are the statistics of the data acquired in which portions of it are plotted in Appendix B. Four particle diameter ranges were used in which one was a cross-linked polystyrene and the other three were glass. All particles were of highest quality in terms of being spherical, solid, and within the range specified. The data in the table is the result of running a baseline noise measurement and then injecting particles by the test sequence given

TABLE 5.1 MEAN OUTPUT DATA

Dia: (10^{-6}m)	32		15-10		25-15		35-25	
Xdcr:	2	3	2	3	2	3	2	3
Baseline:	3.53	6.82	3.40	5.09	6.07	8.39	7.14	5.56
Injection:								
1	4.11	6.77	4.34	5.76	7.56	7.53	5.78	6.09
2	4.52	7.32	4.28	5.87	7.23	7.56	5.40	7.09
3	4.82	7.45	4.33	5.96	8.42	7.94	5.72	7.94
4	4.78	7.47	4.39	6.48	8.59	7.71	6.47	7.81
5	5.03	7.69	4.44	5.76	8.17	7.31	7.20	7.99
6	5.53	7.39	4.58	5.99	9.05	7.43	7.39	8.38
7	5.94	7.87	4.63	6.09	8.53	7.44	8.18	8.79
8	6.47	8.10	4.90	6.45	8.83	6.60	7.36	7.32
9	6.40	8.69	4.81	6.83	8.54	5.88	8.24	6.63
P_{inj}: (10^3)	157.2		614.6		84.8		86.3	
S.G.:		1.06		2.45		2.45		2.45

in Figure 5.1. Each disk of data contains nine files of one particle size at one concentration. Each output value represents the mean of these nine files (9 x 16,384 = 147,456 data points per transducer). In a box, the first disk records the baseline noise (clean fluid), and then each disk following, consists of data from one through nine particle injections. Therefore the notation: Box 8, Xdcr 2, Disk 9-1 relates to the following:

Box 8	32 Micron Polystyrene
Xdcr 2	Data from Transducer 2
Disk 9-1	Disk nine: ninth injection/first file

The mean output values that are columnized in Table 5.1 are plotted in Figure 5.3 for further analysis. For convenience of display, the data points are initially normalized by the first injection value.

The upward trend of both plots is expected as more particles are passing through the acoustic interrogation zone and increasing the sample mean. The downward trend, at higher concentrations, is not as easily explained and could very well be an anomoly in the data. For example, during the eighth injection of the 35-25 micron particles the system pressurization was lost and considerable time was spent making the repair. This certainly accounts for the deviation

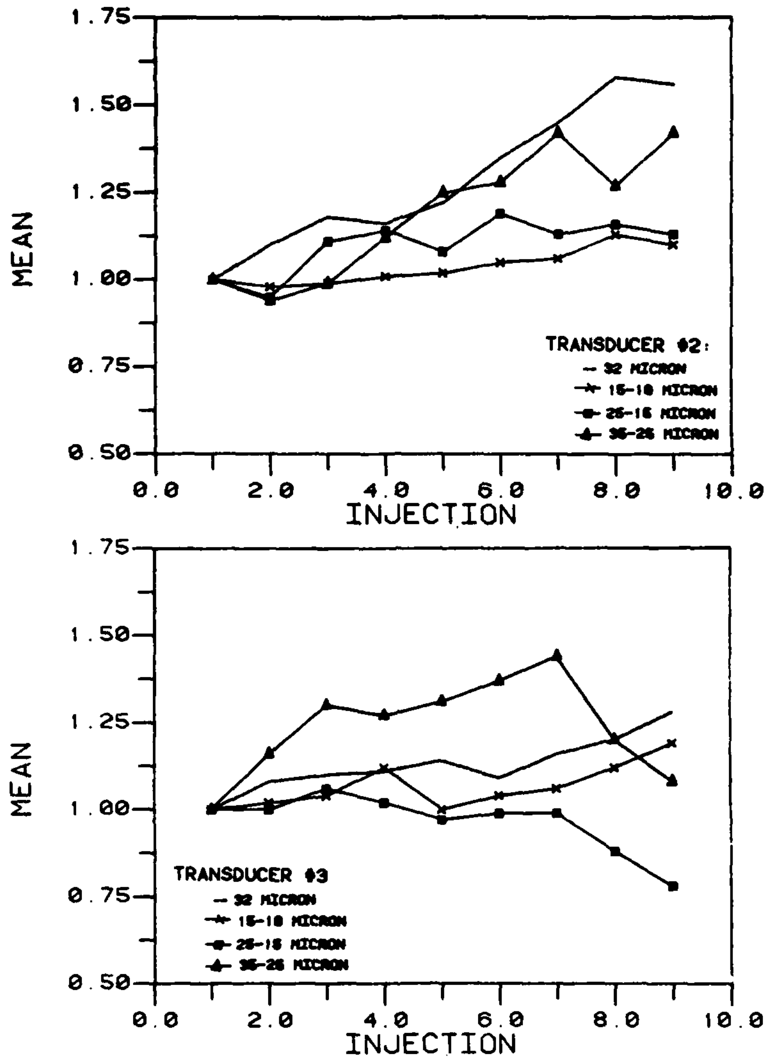

FIGURE 5.3 MEAN OUTPUT DATA

of the eighth injection data point, on the upper plot, but could also have influenced the ninth as well. Also, a tenth 32 micron injection value, that is not in Table 5.1 (nor plotted), is 1.74 and removes that dip.

Of additional interest are the slopes of transducer two's outputs. Corresponding with increasing particle size is the

slope. This is expected since the return reflections are stronger from larger diameter particles. Figure 5.4 illustrates these slopes based on the least squares fitting of the data. The eighth injection point (35-25 micron) was not included for reasons stated above.

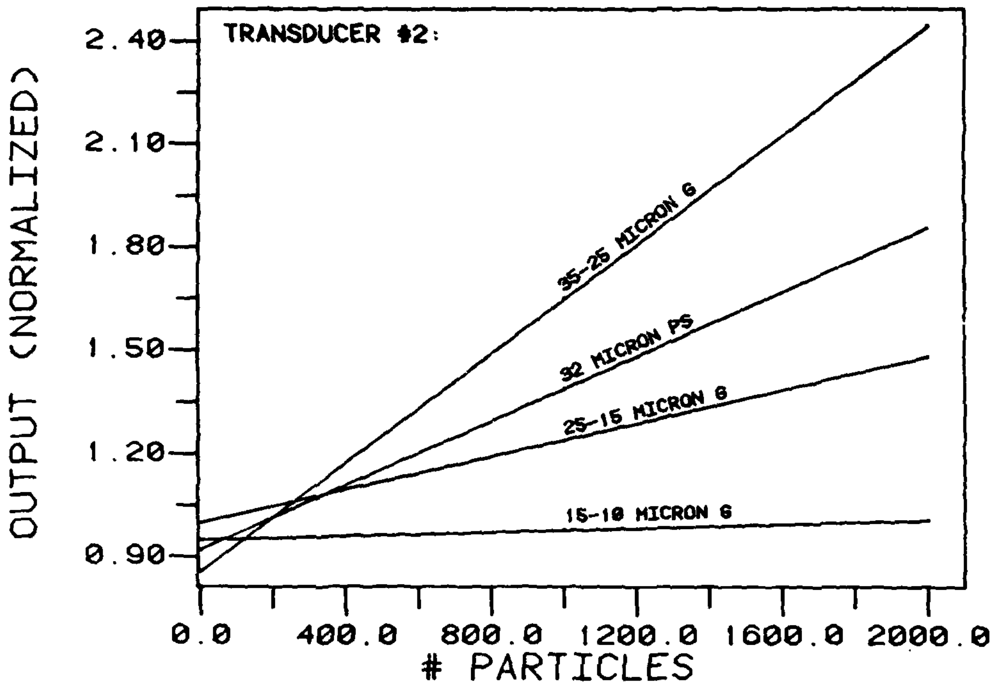

FIGURE 5.4 LEAST SQUARES FIT TO DATA IN TABLE 5.1

In summary:

* The gain in particle concentration enhances the likelihood of detecting a particle and results with an expected growth of the mean output.

* The rate of growth, as larger particles are detected, also increases as expected.

Some additional comments regarding the above Table 5.1:

* The mode and orientation of transducer number 2 is pulse-echo and at 180° from the incident wave. Transducer number 3 is passive and at the 90° position from the incident wave but in the same transverse plane as number 2.

* The baseline noise increased between the second and third columns. This was due to an increase in the receiver's gain.

* In column seven, the baseline noise is considerably higher before the particles were added. The reason for this in unknown, however, the data trend appears satisfactory.

* The specific gravity of the silicone fluid is 0.964 and that of the particles is shown at the bottom of Table 5.1.

* The particles per injection are also noted at the bottom of the table.

Figure 5.5 portrays two statistical methods of examining large quantities of data. One approach is the frequency plot that shows clearly where the concentration of samples lie for a particular output.

The other method displays frequency accumulation and is employed quite often in particle analysis. Other work on-going at the David Taylor Naval Ship R&D Center[19] has refined the use of this method in their research of particle

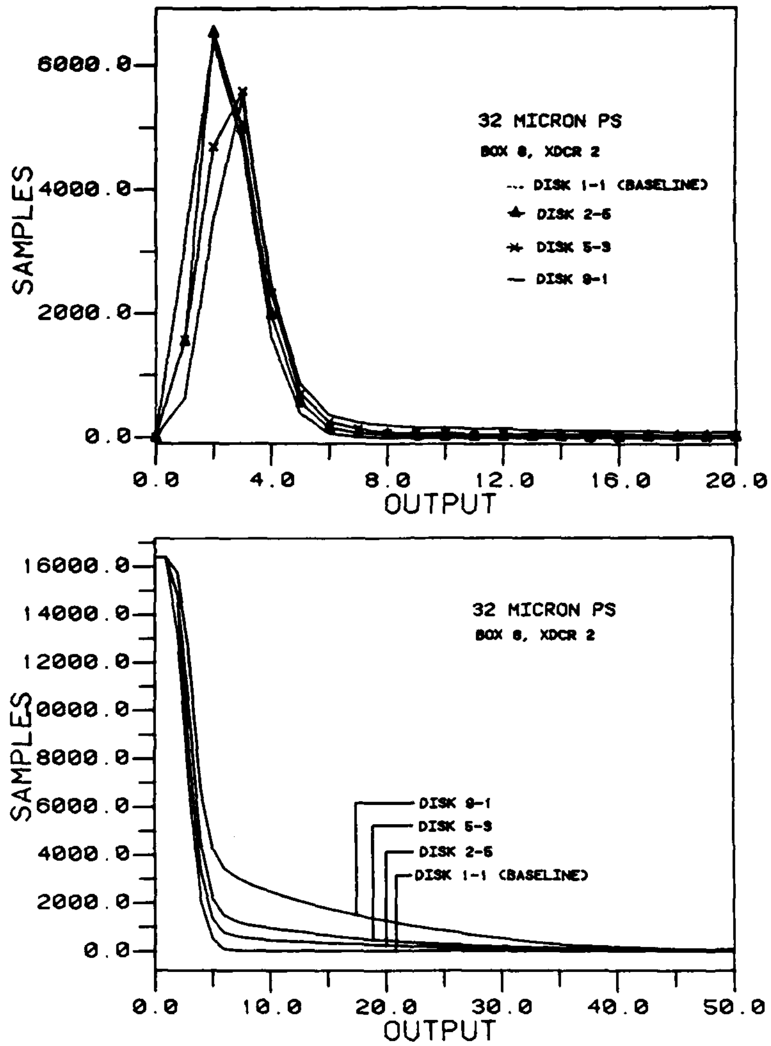

FIGURE 5.5 STATISTICAL METHODS

characterization in hydraulic fluids. Certainly, as can be seen by the two plots, the accumulation is more preferrable in describing the increase in particle concentration.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Summary:

This thesis proved that a focussed ultrasonic beam could detect 15 - 10 micron diameter glass beads in a viscous attenuative fluid. This was accomplished by two factors:

* Operating the transducer with its element in direct contact with the fluid medium. Many of the losses associated with non-essential boundaries, that an acoustic delay line caused, were eliminated.

* Using a transducer which employs a strong degree of focus. The unit primarily used for the results was a 9.5 mm probe with a radiator diameter of 6.4 mm. Even with this small radiator the K_f was 0.28, which is considered strong.

6.2 Conclusion:

Chapter one discussed the thesis objectives with reference to meeting various milestones. The first was to review previous thesis[1] efforts to ensure ultrasonics could be a viable tool. An intense study of ultrasonics was accomplished during the course of this research and no significant discrepancies were noted that would change the final result.

The second milestone was to determine the necessary

```
        mov     #dipric, @#diovrn+2       ; and its priority

                                          ; ready for the big time !!
        .print  #bgnms2                   ; say we are sampling
        CALL    DELAY

                                ; IF SWEEP MODE THEN
                                          ; TAKE OVER THE MONITOR'S KEYBOARD
                                          ; INPUT INTERRUPT SERVICE ROUTINE

        TSTB    SWPMODE                   ; SWEEP MODE ?
        BEQ     ONESWP                    ; NO

        .PRINT  #SWPMSG
        CALL    DELAY
        CALL    DELAY
        CALL    DELAY

        MOV     @#KBIVEC, OLDVEC
        MOV     @#KBIVEC+2, OLDVEC+2

        MOV     #SWPINT, @#KBIVEC         ; TO HELL WITH RMON, WE TAKE OVER !!
        MOV     #340, @#KBIVEC+2          ; INHIBIT INTERRUPTS

        JSR     PC, DELAY
        JSR     PC, DELAY
ONESWP::

        bis     #spmode, @#jsw            ; go into special TT mode
        MOV     #DI1MODE, @#DI1CSR        ; KICK DI1
        MOV     #DIMODE, @#DIOCSR         ; start the di3 hardware

waitt::
        tstb    pgflag                    ; +ve if program in session and
                                          ; -ve error
        beq     waitt                     ;   no flags .. no error
                                          ; here some flag is set

        CALL    DELAY                     ; PAUSE FOR ALL BELLS TO RING
        CALL    DELAY

                                          ; NOTE IN SPECIAL MODE
        BIC     #SPMODE, @#JSW            ; JUST MAKE SURE IT IS UN_SPECIAL MODE

        .print  #SAVmsg                   ; WANT TO SAVE THIS DATA?
        JSR     PC,DELAY
        CALL    GETANS
        CMPB    R0, #'Y

        BEQ     SAVEIT

nosave: .purge  #chan0                    ; purge CHAN0
        JMP     DIHNDL                    ; GO REPEAT PROGRAM

SAVEIT::                                  ; WRITE OUTPUT FILE
        CLR     NXTBLK
        MOV     #NBYTES, R5               ; NO OF TIMES TO WRTE
        MOV     #ONESIZ, R4               ; HOW MANY WORDS EACH TIME
        MOV     #PGEND, R3                ; WHERE TO START

WRIAGN: .writw  #emtarea,#chan0,R3,R4,nxtblk
                                          ; BUFFER TO DISK FILE
        bcs     wrierr                    ; error occurred
```

```
                                        ; r4 = no of samples to take

DIINT::                                 ; interrupt service routine entry pt.
        TSTB    RINGBELL                ; CHECK THE BELL and RING IT
        BEQ     NOBELL
        MOVB    #BELL, @#KBDBUF
NOBELL:
        mov     @#di0dir, r2            ; grab data1 and data2
        mov     @#di1dir, r3            ; grab data3 and garbage

        mov     r2, @#di0dir            ; put it back
        mov     r3, @#di1dir            ; put it back

        movb    r2, (r5)+               ; store data1
        swab    r2                      ; exchange bytes
        movb    r2, (r5)+               ; store data2
        movb    r3, (r5)+               ; store data3

        dec     r4
        BEQ     BUFFUL

more::
        MOV     #DI1MODE, @#DI1CSR      ; clear data ready flag
        MOV     #DIMODE, @#DI0CSR       ; clear data ready flag
        rti                             ; return from interrupt

bufful::                        ; BUFFER FILLED
                                        ;; IF SWEEP MODE AND DID NOT
                                        ;; TYPE G ..RESET BUFFER POINTER
        TSTB    SWPMODE
        beq     quit
                                        ; re-init buffer pointer
                                        ; and counter
        mov     #SAMPCNT, R4            ; NO OF SAMPLES TO FILL BUFFER
        MOV     LOWCORE, R5             ; GET ADDR OF FREE SPACE
                                        ; R5 POINTS TO BUFFER ALWAYS
        br      noSTOP                  ; continuous mode dont stop

quit:   mov     #0, @#di0csr            ; disable interrupts
        movB    #-1, pgflag             ; TELL PROG TO STOP
nostop: rti                             ; return from int

.NLIST

DIERR::
        movb    #dimode, di0csr         ; reset forget this sample
        rti                             ; return from int.


GETANS::                                ;  GET CHAR FROM KEYBOARD
                                        ; WAIT TILL IT IS TYPED
GETCHAR::

;WAITP: MOV     #15000., R0
;       SOB     R0, WAITP

        BIS     #GMODE, @#JSW           ; SPECIAL KEYBOARD MODE
WAIT1:  .TTYIN
        TSTB    R0
        BEQ     WAIT1                   ;WAIT FOR CHAR

WAIT2:  .TTYOUT
;       BCS     WAIT2
        BIC     #GMODE, @#JSW           ; BACK TO UNSPECIAL MODE
```

```
        ADD     #BLKLEN, NXTBLK          ; UPDATE FILE BLOCK POINTER
        SOB     R5, WRIAGN
        ADD     R4, R3                   ; POINT TO NEXT START

over::
                                         ; make sure everything is off !
;       mov     #0, @#di0csr             ; disable interrupts
;       CALL    DELAY
        .close  #chan0                   ; SAVE THE FILE FOR NOW

        .PRINT  #RENPRT
        .CSISPC #OUTSPC, #DEFEXT         ; GET NEW NAME for file
                                         ; to rename it
        mov     #inspcs, r4
        mov     #RENNAM, r5
        mov     #4, r3                   ; init # of words to move
again2: mov     (r4)+, (r5)+             ; move radix-50 name to below
                                         ; DI-DAT AREA
        sob     r3, again2

        .RENAME #EMTAREA, #7, #filptr    ; yes !


        JMP     DIHNDL                   ; loop through program again !
                                         ; EXIT ? WITH CTRL-C


                                         ; I/O ERROR SECTION
diskfull::
wrierr::                                 ; possibly the disk is full
                                         ; so error not serious
        mov     #0, @#di0csr             ; disable interrupts anyway
        movb    #-1, pgflag              ; tell program to stop
        tstB    @#ERRBYT                 ; r0 <> 0 if diskful
        beq     skip2                    ; no error
                                         ; yes, ..so error..
        bisb    #wribit, pgstatus        ; identify error as write error
skip2::

                              ; ERROR PROCESSING

errrtn::                                 ; we exit the program thru here
                                         ; to process possibly any errors
                                         ; that occurred

        bitb    #wribit, pgstatus        ; was there a write error ?
        beq     DATRTN                   ; no ..check next
        .print  #wrimsg                  ; say oops !!
        .EXIT                            ; take an exit

datrtn::
        bitb    #datbit, pgstatus        ; was there a data overrun ?
        beq     bye                      ; no ..check next
        .print  #ovrnmsg                 ; say oops !!
        .EXIT                            ; take an exit
                              ; PROGRAM HERE ONLY ON FATAL ERRORS
bye:    .print  #exitmsg                 ; done sampling all over
                                         ; too many headaches
END::   .exit                            ; out to monitor


                                         ; register assignments
                                         ; r5 --> next byte to write to
```

```
PSKIP1:

        .print  #prmpt2                 ; WANT CONTINUOUS SWEEP ?
        CALL    DELAY
        CALL    GETANS                  ; GO GET ANSWER
        cmpB    r0, #'Y                 ; yes ?
        bne     pskip2                  ; no
        incb    swpmode                 ; yes set flag

        .PRINT  #NEWLIN

                                        ; setup buffer area
pskip2:
        mov     limit+2, lowcore
        .fetch  lowcore, #filptr        ; load disk handler
        bcs     feterr                  ; if error
        mov     r0, lowcore             ; this is the new low limit
                                        ; FOR PROGRAM ..so save it
        .enter  #farea, #chan0, #filptr, #-1
                                        ; open file for output
                                        ; len=-1 gives largest
                                        ; space on disk
        bcs     enterr                  ; if error
        br      skip                    ; skip error section

                                ; USR ERRORS
feterr: .print  #fetmsg                 ; fetch error
        .EXIT
enterr: .print  #entmsg                 ; file enter error
        .EXIT

                                        ; ensure buffer does not
                                        ; overrun RESIDENT MONITOR
SKIP::
        MOV     #ONESIZ*NBYTES, R2      ; word count in buffer
        ASL     R2                      ; to byte count
        ADD     LOWCORE, R2
        MOV     R2, REQADR

        .SETTOP #-2                     ; ask for buffer space
                                        ; USR swapped out
        MOV     R0, HICORE              ; save max addr. allowed
        CMP     R0, REQADR              ; enough space ?
        BGT     OK                      ; yes
        .PRINT  #NSPACE                 ; say cannot allocate space
        .EXIT                           ; QUIT !!

OK:
                                ; INIT FLAGSAND POINTERS
        clr     r0                      ; r0 = # of words written to
                                        ; disk .. so far none
        mov     #SAMPCNT, R4            ; NO OF SAMPLES TO FILL BUFFER
        MOV     LOWCORE, R5             ; GET ADDR OF FREE SPACE
                                        ; R5 POINTS TO BUFFER ALWAYS


                                        ; ready to sample
                                        ; set up di3 hardware
                                        ; interrupt service routine
        .NLIST
DISTUP::
        mov     #diint, @#divec         ; load interrupt serv. routine addr.
        mov     #diprio, @#divec+2      ; isr executes at this priority ( 7 )

        mov     #dierr, @#diovrn        ; load overrun error int vec too !
```

```
        DI1MODE = 000060                 ; MODE FOR DI1, NO INTERRUPTS

        ascval = 177600                  ; mask to leave ascii value
        hibyte = 177400                  ; mask for higher byte of a word

        dierbt = 040000                  ; error bit in csr

        chan0 = 0                        ; channel 0 for disk operations

; ASSEMBLER DOES ARITHMETIC
; BLKLEN = desired # OF BLOCKS PER TRANSDUCER
; THIS IS THE ONLY CONSTANT TO CHANGE IF A
; DIFFERENT NUMBER OF SAMPLES IS TO BE TAKEN

        .LIST

        BLKLEN = 32.
        blksiz = 256.                    ; no of words in a blk
        ONESIZ = BLKLEN*blksiz           ; total # of words PER TRANSDUCER
        BUFSIZ = NBYTES*ONESIZ           ; TOTAL NO OF WORDS IN BUFFER
        NBYTES = 3                       ; no of bytes filled on
                                         ; each sample of the DIGITAL IN
        sampcnt = 2*ONESIZ               ; # of samples taken to fill
                                         ; buffer EACH TRANDUCER' SPACE
        wribit = 10                      ; error bits in pgstatus
        bufbit = 100
        datbit = 1000
        gmode =  10000                   ; bit 12
        SPMODE = 10100                   ; bits set while ringing bell
                                         ; special mode TT bit 12
                                         ; inhibit TT wait bit 6
        JSW = 44                         ; JOB STATUS WORD ADDR.
        ERRBYT = 52
        pglimit = 50                     ; addr of program hi limit
        rmonaddr = 54                    ; addr of start of RMON
        usrloc = 266                     ; offset into RMON of USR location

DIHNDL::                     ; START OF MAIN PROGRAM
                                         ; RETURNS HERE IF DATA IS DISCARDED
                                         ; AFTER GOING THRU PROGRAM

        .SRESET                          ; SOFT RESET, RELEASE
                                         ; EVERYTHING TO START THIS LOOP
                                         ; setup preamble
        .print #bgnmsg                   ; say demo

        CLRB    RINGBELL                 ; no bells until wanted
        CLRB    SWPMODE                  ; default sweep mode = Continuous

        clrb    pgflag                   ; program can run
                                         ; -ve means stop program
                                         ; +ve means write a buffer
        clrb    pgstatus                 ; error status for program
        clr     nxtblk                   ; start from block 0 of file
        clr     nxtblk                   ; file write block offset

        .print #prmpt1                   ; want bells during ints. ?

        JSR     PC, DELAY
        call    GETANS                   ; GET ANSWER

        cmpB    r0, #'Y
        bne     pskip1
        movb    #bell, ringbell
```

```
        .TITLE DI3
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;                                                              ;
;                POLYMER PROCESSING PROGRAM                    ;
;                                                              ;
;     DIx.MAC  ACQUIRES  THE DATA THROUGH THE  "DIGITAL        ;
;     IN"  MODULE OF THE  MINC-11 WHEN  A  STROBE (LOW)        ;
;     INTERRUPT  IS  RECEIVED  FROM  THE  MD-702  PEAK         ;
;     DETECTOR.                                                ;
;                                                              ;
;     BUFFER  SPACE  IS ALLOCATED AT RUNTIME.    OUTPUT        ;
;     FILE  IS  FIRST WRITTEN TO  DI.DAT  AND THE  USER        ;
;     MUST RENAME THE FILE:  filename.DAT                      ;
;                                                              ;
;     THE EXECUTABLE PROGRAM WILL THEN BE:  DIx.SAV            ;
;                                                              ;
;     WHERE x ENCOMPASSES TWO VERSIONS:                        ;
;                  x=2  FOR A TWO   TRANSDUCER ARRAY           ;
;                  x=3  FOR A THREE TRANSDUCER ARRAY           ;
;                                                              ;
;                                    L. OSLUND 3-24-84         ;
;                                                              ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; FILE: DI3.MAC

        .NLIST
        .ENABL LC
        .nlist me
        .nlist cnd

; CONSTANTS AND MCALLS

        .MCALL  .EXIT, .PRINT, .GVAL, .CSISPC
        .MCALL  .FETCH, .ENTER, .WRITW, .RENAME
        .MCALL  .PURGE, .CLOSE, .TTINR, .TTOUTR
        .MCALL  .SETTOP, .SRESET, .TTYIN, .TTYOUT

        cr = 15
        lf = 12
        bell = 7
        yes = 131
        no = 116
        KBIVEC= 60                      ; CONSOLE TERMINAL INPUT
                                        ; INTERRUPT VECTOR
        kbdin = 177562                  ; keyboard input buffer
        KBDBUF = 177566                 ; keyboard output buff

        divec = 120                     ; data ready int. vec.
        diovrn = divec+4                ; data overrun int. vec.
        di0csr = 171160                 ; 1st control status reg addr.
        di1csr = 171170                 ; 2nd control status reg addr.
        di0dir = di0csr+2               ; 1st data input register
        di1dir = di1csr+2               ; 2nd data input register

        diprio = 340                    ; priority 7 for di3 hardware

        dimode == 040172                ; di control status reg. bits
                                        ; ext trig enb bit 1
                                        ; +ve strobe enb bit 3
                                        ; defeat panel swtchs bit 4
                                        ; +ve data bit 5
                                        ; int. on data rdy bit 6
                                        ; int on error bit 14
```

APPENDIX A

DIGITAL MINC-11 SOFTWARE

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the user some confidence of the number of "big" particles in the entire flow. Such analysis is current at General Electric's Corporate R&D Center and is described[18] in good detail. The method assumes the Poisson model with a homogeneous population in which only a small fraction (less than 10%) of the population is sampled.

4. Discussed in Chapter 4 is the linearity of the data acquisition system. Further work needs to be done in computerizing the linearization process, especially for developing the necessary accuracy, for use in the statistical analysis above.

An elaborate signal processing system became operational with input to a computer for high speed data acquisition.

The second major objective to plot a distribution of particle sizes with their respective concentrations was achieved in some part as shown in Figure 5.4. Additional software in the area of signal processing and statistics is primarily required for a more thorough application.

6.3 Future Work:

1. The intent of this project is to analyze various sizes, shapes, and densities of particles in a cool, attenuative fluid and apply this knowledge to determine the quality of mix in polymers. The continuation with this particle characterization in the fluid model still needs to be done.

2. Using a high temperature transducer up to 400°C (750°F) is well within the realm according to work previously accomplished[17] and tested rigorously for 400 days. This avenue is worth some real consideration in lieu of regressing back to the quartz delay line, for use with the high temperature polymers,

3. The interrogation zone is made small for the increased sensitivity of the transducer to receive reflections from small particles. In doing so, not all particles in the outer regions of the focal zone are observed. Therefore it is necessary to develop a statistical approach that would give

processing. This was a significant accomplishment which met all of the above requirements. As noted in Appendix C, the peak detectors are able to process each individual signal in lieu of the typical averaging effect most peak detectors have. The system also operates up to 10 KHz (10,000 samples per second) which is necessary to interrogate maximum flow velocities of 1 to 1.5 m/s (3.8 to 5 f/s). This is computed by knowing the amount of time required for a particle to traverse one half of the acoustic beam width to satisfy the Nyquist sampling rate. For an example, if we assume a plug flow through an one inch extruder die, and specific gravity of the material of one, then this equates to approximately 1285 pounds per hour. In terms of a shipboard hydraulic system, the flow rates are designed not to exceed 20 f/s [16], however, this greatly exceeds the maximum velocity criteria above. Therefore, flow velocities should be known before an application is made.

The final milestone is to return to the polymer extruder and apply the knowledge gained from the model. This was not accomplished except in designing a multi-transducer polymer test section.

The first major objective to develop a non-destructive on-line system capable of detecting particles of a minor component in a viscous fluid was accomplished. A continuation of previous efforts were broadened with the ability to identify individual particles as small as 15 - 10 microns.

Ideally, increasing the radiator's diameter would seem to be the key to decreasing the focal spot, yet the physical diameter of the transducer, will eventually become limiting. In fact, a compromise between the diameter and the frequency are essential.

One assumption made earlier was that particles are evenly dispersed throughout the medium. That is not true in most cases and having a proper data sampling rate is necessary. This frequency (rep rate) is calculated by knowing the fluid's volume flow rate through the interrogation zone and dividing by one half the volume of the interrogation zone. This gives the Nyquist (minimum) frequency of pulsing the particle twice as it passes through the interrogation zone. The objective is to gain the minimum data such that the actual peak can be reconstructed using digital signal processing methods.

The third milestone eliminated the temperature consideration and specified testing with known concentrations of particles as well as known particle dimensions. The fluid model would then serve as a learning tool and calibrator for particle sizing. The first part was done although insufficient tests were run to consider that particle calibration was accomplished.

The fourth milestone was to design a signal processing system to enable accurate, quick, and reliable data gathering and

parameters to enable particle detection. Thus far the emphasis has been in decreasing the focal spot and maximizing the acoustic intensity. The analysis assumes the following constants:

Focal distance, F

Velocity of sound through the medium, c

Pressure amplitude, P/P_o

Then, $$F_z \propto \frac{1}{f D}2$$

$$B_w \propto \frac{1}{f D}$$

$$I \propto D^2 f^2$$

where:

$f =$ Frequency, Hz

$D =$ Radiator diameter, m

Given that the frequency can be easily varied between 1MHz to 10MHz, and the diameter can vary twice, it is then reasonable to expect that the frequency would be the parameter to optimize. But another factor which needs consideration is the following:[1,11]

$$\alpha_{new} \simeq \alpha_{prev} (f_{new}/f_{prev})^2$$

The gain realized previously, by increasing the frequency, now results in an considerable loss through attenuation.

```
        RETURN

DELAY::                                         ; DELAY LOOP
        MOV     1500., R0
INDEL:  NOP
        SOB     R0, INDEL
        RTS     PC


SWPINT::                                        ; THIS IS THE ENTRY POINT FOR
                                                ; THE KEYBOARD
                                                ; INPUT INTERRUPT SERVICE
                                                ; ROUTINE WHILST
                                                ; THE DI3 HARDWARE IS ACTIVE
        MOVB    @#KBDIN, R0
        CMPB    R0, #'G
        BNE     NOTYET
        MOVB    #-1, PGFLAG                     ; SIGNAL PROGRAM TO STOP
        MOV     #0, @#DIOCSR                    ; STOP DI3 HARDWARE

                                                ; PUT RT-11 VECTORS BACK
        MOV     OLDVEC, @#KBIVEC                ; THE VECTOR
        MOV     OLDVEC+2, @#KBIVEC+2            ; ITS PRIORITY

        BIC     #SPMODE, @#JSW                  ; MAKE SURE THE KEYBOARD IS IN
                                                ; UN-SPECIAL MODE
NOTYET:
        RTI

OLDVEC::        .WORD
OLDRTC::        .WORD


        .LIST
                                      ;; DATA AREA

pgstatus::      .byte 0                         ; program error flag, identifies error
pgflag::        .byte 0                         ; program continuation flag
                                                ; do nothing when 0
                                                ; stop  -ve
                                                ; write buffer +ve
RINGBELL::      .BYTE                           ; contains octal 7 for bell to ring
swpmode::
                .byte                           ; flag for continous sweep
                .EVEN
lowcore::       .word                           ; lowest addr. space at run time
hicore::        .word                           ; and  highest.
nxtblk::        .word                           ; pointer to next available block
                                                ; on output file
counter::       .word
bufptr::        .word
lstptr::        .word                           ; pointer to present buffer
nxtptr::        .word                           ; pointer to next buffer to be used

DEFEXT:         .WORD   0,0,0,0                 ; default extensions for CSI
filptr::        .rad50 /DY1/                    ; FILE BLOCK FOR RENAMING FILE
                .rad50 /DI     DAT/
RENNAM::        .RAD50 /DY1/
                .RAD50 /   /
                .RAD50 /   /
                .RAD50 /   /
outspc::        .BLKW   3*5                     ; csi block
inspcs::        .BLKW   6*4
farea::         .blkw 10.                       ; emt arg list
```

```
emtareas::      .blkw 5.

                .NLIST BIN
                              ; MESSAGE TEXT

CLRSCN: .BYTE   33,133,62,112, 0
NEWLIN: .BYTE   15,12, 15,12, 0

renprt: .BYTE   12,15, 33,133,62,112, 33,133,60,155
        .ascii  / ENTER NEW FILE NAME       /
        .BYTE   33,133,60,155, 10, 200

bgnmsg:
        .BYTE   33,133,62,112, 33,133,60,73,60,110
        .ascii  <cr><lf>/        DIGITAL-IN  DATA/<33><43><66>
        .ascii  <cr><lf>/     THREE XDCR ACQUISITION/<33><43><66>
        .ASCII  <cr><lf><cr><lf><cr><lf>
        .BYTE   0

prmpt1: .BYTE   12,15,12,15,33,133,60,155
        .ascii  /   DO YOU WANT THE BELL TO                /<cr><lf>
        .ascii  /   RING DURING SAMPLING ? (Y or N) :     /
        .BYTE   33,133,60,155, 10, 200

prmpt2: .BYTE   12,15,12,15,33,133,62,112, 33,133,60,155
        .ascii  /   DO YOU WANT CONTINUOUS                 /<cr><lf>
        .ascii  /               SAMPLING ? (Y or N) :     /
        .BYTE   33,133,60,155, 10, 200

SAVMSG: .BYTE   12,15,33,133,62,112, 33,133,60,155
        .ascii  /   DO YOU WANT TO SAVE                  /<cr><lf>
        .ascii  /   THIS SET OF DATA ? (Y or N) :        /
        .BYTE   33,133,60,155, 10, 200

SWPMSG: .BYTE   33,133,62,112, 33,133,60,155 ,15,12
        .ASCII  <CR><LF>/   TYPE  G   WHEN READY :      /
        .BYTE   33,133,60,155, 10, 200

bgnms1: .BYTE   33,133,62,112, 33,133,60,155 ,15,12
        .ASCII  <CR><LF>/READY TO TAKE SAMPLES /
        .BYTE   33,133,60,155, 10, 200

bgnms2: .BYTE   33,133,62,112, 33,133,60,155 ,15,12
        .ASCII  <CR><LF>/   HOLD ON .... TAKING SAMPLES /
        .BYTE   33,133,60,155, 10, 200

exitmsg: .BYTE  33,133,62,112, 33,133,65,155 ,15,12
        .ASCII  <CR><LF>/   FATAL ERROR:/<CR><LF>
        .BYTE   33,133,67,155, 15,12
        .ASCII  /  MAY BE OUT OF DISK SPACE.... BYE BYE/
        .BYTE   33,133,60,155, 15,12, 0

FETmsg:.BYTE    33,133,62,112, 33,133,65,155 ,15,12
        .ASCII  <CR><LF>/   FATAL ERROR:/<CR><LF>
        .BYTE   33,133,67,155, 15,12
        .ASCII  /  ?-FETCH: CANNOT LOAD DISK HANDLER ....BYE BYE/
        .BYTE   33,133,60,155, 15,12, 0

ENTmsg: .BYTE   33,133,62,112, 33,133,65,155 ,15,12
        .ASCII  <CR><LF>/   FATAL ERROR:/<CR><LF>
        .BYTE   33,133,67,155, 15,12
        .ASCII  /  ?-ENTER: COULD NOT OPEN OUTPUT FILE ...BYE BYE/
        .BYTE   33,133,60,155, 15,12, 0

WRImsg: .BYTE   33,133,62,112, 33,133,65,155 ,15,12
        .ASCII  <CR><LF>/   FATAL ERROR:/<CR><LF>
```

```
        .BYTE   33,133,67,155, 15,12
        .ASCII  /  ?-WRITE: COULD NOT WRITE OUTPUT FILE/<CR><LF>
        .ASCII  /  MAY BE OUT OF DISK SPACE.... BYE BYE/
        .BYTE   33,133,60,155, 15,12, 0

NSPACE:
        .BYTE   33,133,62,112, 33,133,65,155 ,15,12
        .ASCII  <CR><LF>/   FATAL ERROR:/<CR><LF>
        .ASCII  <CR><LF>/   FATAL ERROR:/<CR><LF>
        .BYTE   33,133,67,155, 15,12
        .ASCII  /  ?-BUFFER:... DATA OVER RUN INTO MONITOR CODE/
        .BYTE   33,133,60,155, 15,12, 15,12, 0

OVRNMSG:
        .BYTE   33,133,62,112, 33,133,65,155 ,15,12
        .ASCII  <CR><LF>/   FATAL ERROR:/<CR><LF>
        .ASCII  <CR><LF>/   FATAL ERROR:/<CR><LF>
        .BYTE   33,133,67,155, 15,12
        .ASCII  /  ? DI3 HARDWARE:... DATA OVERRUN /
        .BYTE   33,133,60,155, 15,12, 15,12, 0

        .even
.LIST

REQADR::        .WORD

LIMIT::         .LIMIT                  ; program limits
PGEND::
        .end    dihndl                  ;; end of main program
```

```
        .TITLE  B2W3
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;                                                                     ;
;                     POLYMER PROCESSING PROGRAM                      ;
;                                                                     ;
;     CHANGES THE OUTPUT FROM THE  DI-DATA  ACQUISITION               ;
;     PROGRAM **DIx** (8-BIT BYTES TO 16-BIT WORDS) FOR               ;
;     USE IN THE FOLLOW-ON FORTRAN  PROGRAM  **FREQMx**               ;
;                                                                     ;
;     THIS MACRO PROGRAM MUST BE  LINKED  WITH  FORTRAN               ;
;     PROGRAM **NB2Wx**.                                              ;
;                                                                     ;
;     PROCEDURE:  COMPILE/FORTRAN NB2Wx.FOR                           ;
;                 COMPILE/MACRO B2Wx.MAC                              ;
;                 LINK B2Wx,NB2Wx                                     ;
;     THE EXECUTABLE PROGRAM WILL THEN BE:  B2Wx.SAV                  ;
;                                                                     ;
;     WHERE x ENCOMPASSES TWO VERSIONS:                               ;
;                 x=2  FOR A TWO   TRANSDUCER ARRAY                   ;
;                 x=3  FOR A THREE TRANSDUCER ARRAY                   ;
;                                                                     ;
;                                     L. OSLUND 3-24-84               ;
;                                                                     ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; FILE: B2W3.MAC
; OUTPUT TO: DIOUT2.DAT

        .ENABL  LC

        .mcall  .enter, .readw, .close, .print
        .mcall  .lookup, .writw, .exit, .fetch

.NLIST ME
.NLIST  CND

lf = 12
cr = 15
inchan = 0                                      ; channel for input
outchan = 1                                     ; for output

KBDOUT = 177566
BELL = 7
blksiz = 256.
insiz = blksiz*3                                ; 3 blocks of data at a shot
outsiz = INSIZ*2                                ; each input block gives
                                                ; 2 output blocks

ERRBYT = 52

B2W3::
        .print  #bgnmsg                         ; identify itself

        .fetch  #free, #outfile                 ; load disk handler
        bcs     feterr                          ; if error

                                                ; 2(R5) IS ADDR OF INPUT
                                                ; FILE FROM NB2W3.FOR
        .lookup #emtarea, #INCHAN, 2(R5)        ; check out input file
        bcs     lukerr                          ; file not found

        .enter  #emtarea, #OUTCHAN, #outfile, #-1
                                                ; open file for output
                                                ;  -1 gives max space
```

```
        bcs     enterr                          ; can't find space

        clr     nxtblk                          ; init file block pointers
        clr     inblk

loop::
        .readw  #emtarea, #INCHAN, #inbuf, #insiz, INBLK
                                                ; reads next 3 blocks
        bcs     readerr                         ; may be end of file
        ADD     #3., INBLK

                                                ; now format data read

                                                ; pointer into array elements
        mov     #inbuf, r1                      ; start of data area
        mov     #outbuf, r2                     ; and output

again::                                         ; r0 = # of words read
        asl     r0                              ; no of bytes to transfer
;       MOV     #BELL, @#KBDOUT                 ; RING BELL

next::
        movb    (r1)+, (r2)                     ; move byte to word
        inc     r2                              ; point to higher byte
        clrb    (r2)+                           ; clear it and point to next
        sob     r0, next                        ; serve all 3 transducers
                                                ; .. by moving all the bytes
                                                ; out !

                                                ; now write formatted data

        .writw  #emtarea, #outchan, #outbuf, #outsiz, nxtblk
        bcs     wrierr                          ; if error

        add     #6., nxtblk                     ; update output file block
                                                ; pointer

        jmp     loop                            ; go for more processing


                                        ;error processing

enterr: .print  #entmsg                         ; cry out loud !
        br      over
feterr: .print  #fetmsg
        br      over
lukerr: .print  #lukmsg
        br      over
wrierr:
        tst     r0
        beq     over
        .print  #wrimsg
        br      over
readerr:
        tst     @#errbyt                        ; did error occur
        beq     over                            ; no, end of file
        .print  #entmsg
        br      over
;enterr:        .print  #entmsg
;       br      over

over::
        .close  #inchan                         ; close data files
        .close  #outchan
```

```
        .print  #extmsg

        .exit

                                        ; data area

INBLK::         .WORD
nxtblk::        .word   0
infile:         .word 0,0
outfile:
        .rad50  /DY0/
        .rad50  /SAMPLEDAT/                     ; output: SAMPLE.DAT

entarea:
        .blkw   10
                                        ; message area
.nlist  bin

bgnmsg: .ascii  <cr><lf>/*** three transducer operation *** /
        .asciz  <cr><lf>/ /<cr><lf>
fetmsg: .asciz  <cr><lf>/*** fetch error occurred ***/<cr><lf>
wrimsg: .asciz  <cr><lf>/*** write error occurred ***/<cr><lf>
entmsg: .asciz  <cr><lf>/*** enter error occurred ***/<cr><lf>
lukmsg: .asciz  <cr><lf>/*** lookup error occurred ***/<cr><lf>

extmsg: .asciz  <cr><lf>/*** program over ....exitting... ***/<cr><lf>
;fetmsg:         .asciz  /*** fetch error occurred ***/

inbuf:: .blkw   insiz

outbuf::
data1:: .blkw   OUTSIZ/3
data2:: .blkw   OUTSIZ/3
data3:: .blkw   OUTSIZ/3

limit:  .limit
free:
        .end
```

```
      PROGRAM MB2W3
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                        C
C                POLYMER PROCESSING PROGRAM              C
C                                                        C
C    CHANGES THE OUTPUT FROM THE  DI-DATA  ACQUISITION   C
C    PROGRAM **DIx** (8-BIT BYTES TO 16-BIT WORDS) FOR   C
C    USE IN THE FOLLOW-ON FORTRAN  PROGRAM   **FREQx**   C
C                                                        C
C    THIS FORTRAN PROGRAM MUST BE  LINKED  WITH  MACRO   C
C    PROGRAM **B2Wx**.                                   C
C                                                        C
C    PROCEDURE:  COMPILE/FORTRAN MB2Wx.FOR               C
C                COMPILE/MACRO B2Wx.MAC                  C
C                LINK B2Wx,MB2Wx                         C
C    THE EXECUTABLE PROGRAM WILL THEN BE:  B2Wx.SAV      C
C                                                        C
C    WHERE x ENCOMPASSES TWO VERSIONS:                   C
C                x=2  FOR A TWO   TRANSDUCER ARRAY       C
C                x=3  FOR A THREE TRANSDUCER ARRAY       C
C                                                        C
C                                    L. OSLUND 3-24-84   C
C                                                        C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      INTEGER*2       INFILE(4)
      BYTE            CHANAM(12), ANS
      DATA            CHANAM/'D','Y','1',6*' ','D','A','T'/
      EXTERNAL B2W3
C
C MACRO PROGRAM DOES THE FORMATTING
C
      TYPE 15
15    FORMAT(' THIS PROGRAM CHANGES THE BYTES TO WORDS')
20    TYPE 25
25    FORMAT(' INPUT FILE NAME ? :      ',$)
      ACCEPT 35, (CHANAM(I), I=4, 9)
35    FORMAT(6A)
C
      CALL IRAD50(12, CHANAM, INFILE)
      LKCHAN = IGETC ()
      IF (LKCHAN .LT. 0) GOTO 98
      LCODE = LOOKUP(LKCHAN, INFILE)
      IF (LCODE .LE. 0) GOTO 196
C
C FILE FOUND
C
      CALL CLOSEC(LKCHAN)
      CALL B2W3(INFILE)
      GO TO 9999
C
40    TYPE 45
45    FORMAT(' DO YOU WANT TO FORMAT ANOTHER FILE ?
      1      (Y or N) :  ',$)
      ACCEPT 55, ANS
55    FORMAT(A)
      IF (ANS .EQ. 'Y') GOTO 20
      GO TO 9999
C
C ERROR PROCESSING
C
98    TYPE 99
99    FORMAT(' FATAL ERROR:      NO CHANNELS AVAILABLE'//)
      GOTO 9990
```

```
C
C LOOKUP ERROR
C
196     IF (LCODE .LT. 0) GOTO 198
        TYPE 197
197     FORMAT(' THE INPUT FILE IS EMPTY'//)
        GOTO 9990
198     TYPE 199
199     FORMAT(' INPUT FILE DOES NOT EXIST'//)
9990    GOTO 40
C
9999    CALL EXIT
        END
```

APPENDIX B

DATA TABLES

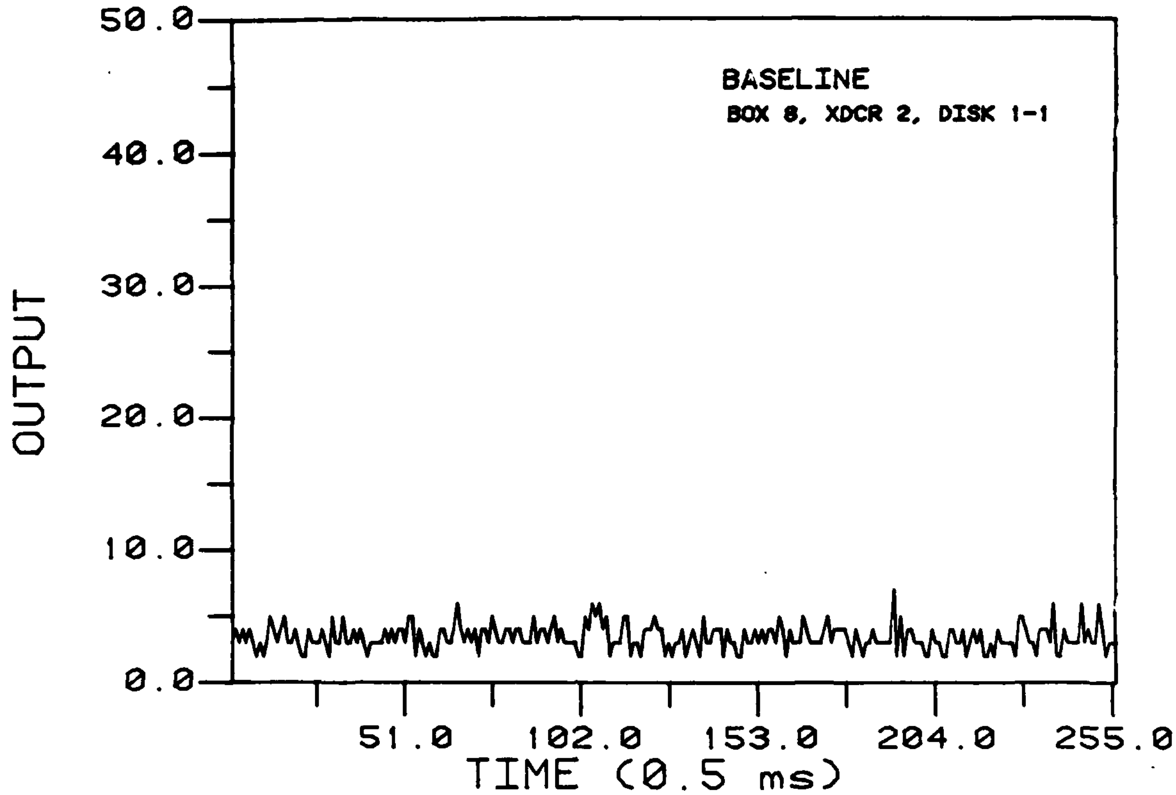
CONTENTS

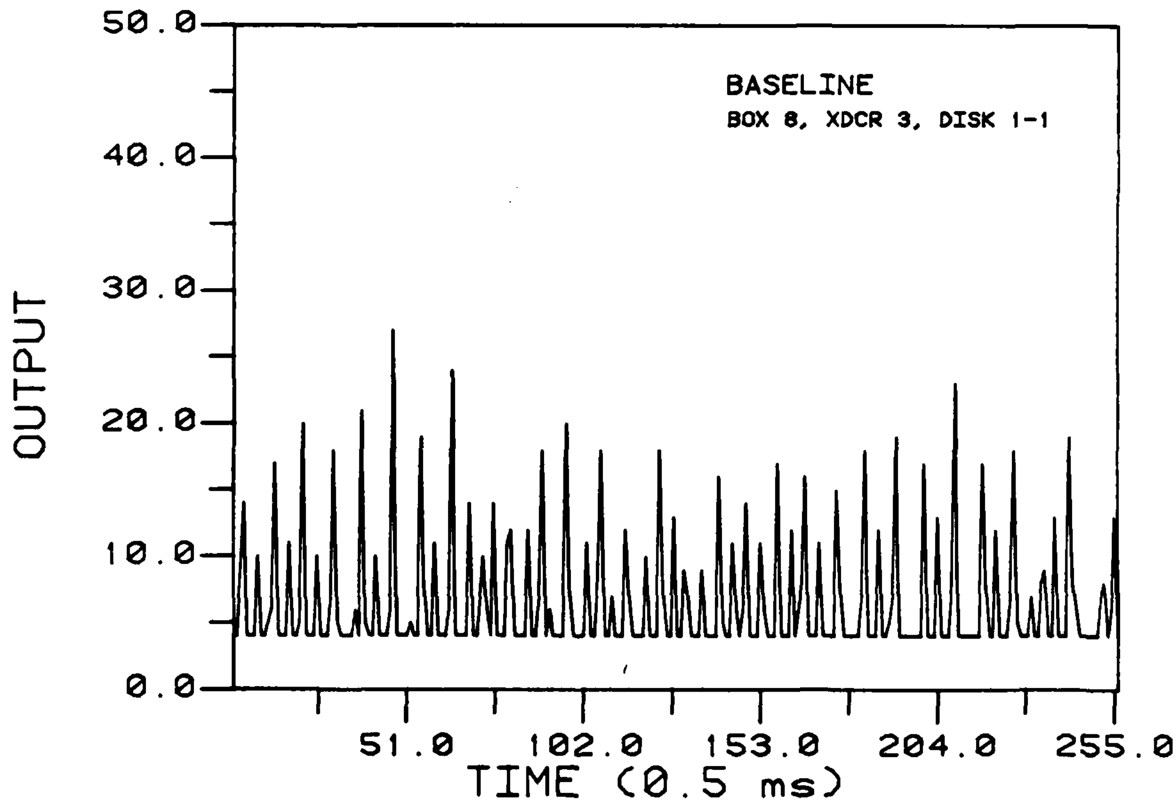
Baseline represents data acquired on an operational system without particles.

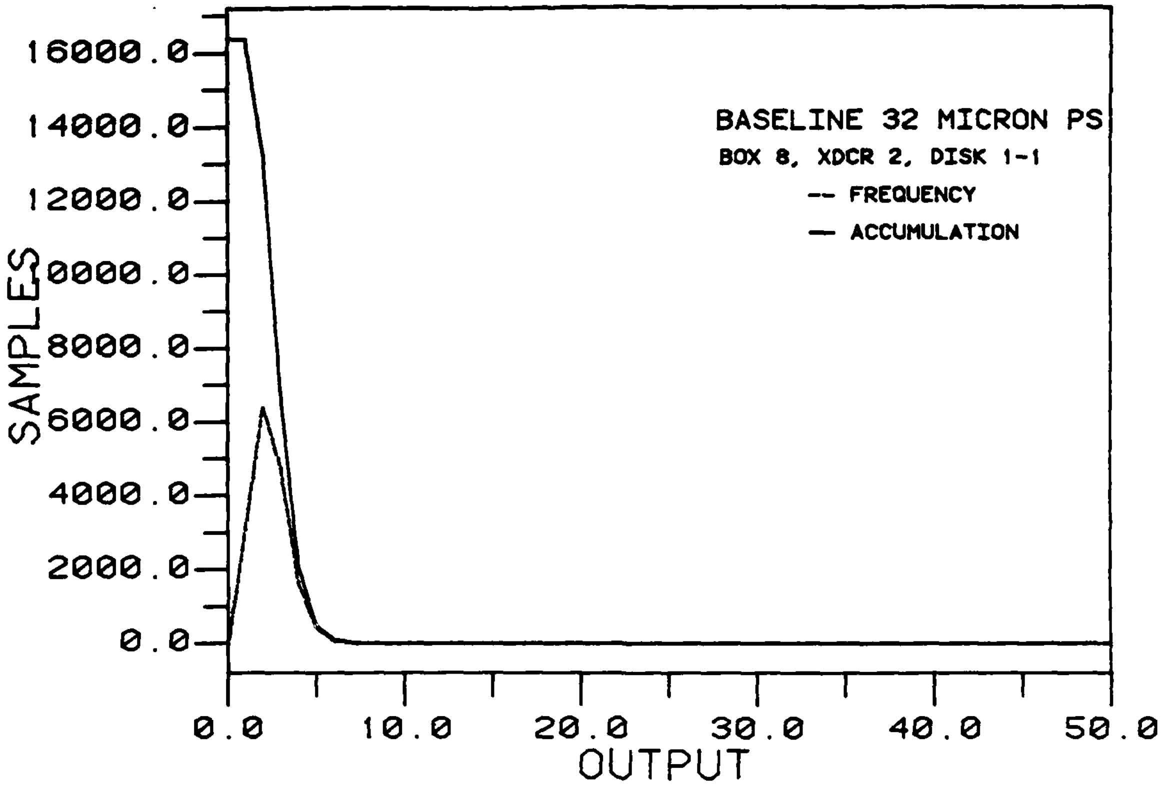
Disk x-y indicates x concentration and the y^{th} file at that concentration.

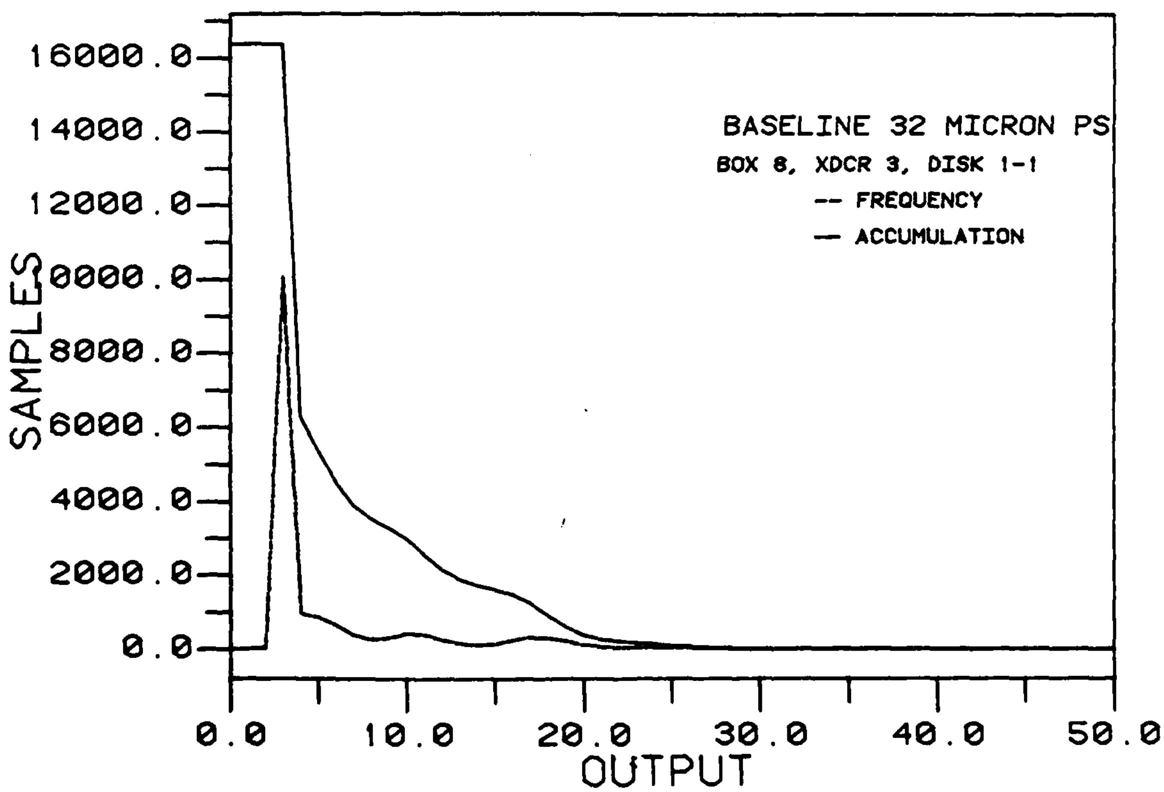
Transducer two is pulse-echo while transducer three is passive and positioned 90^{o} from two.

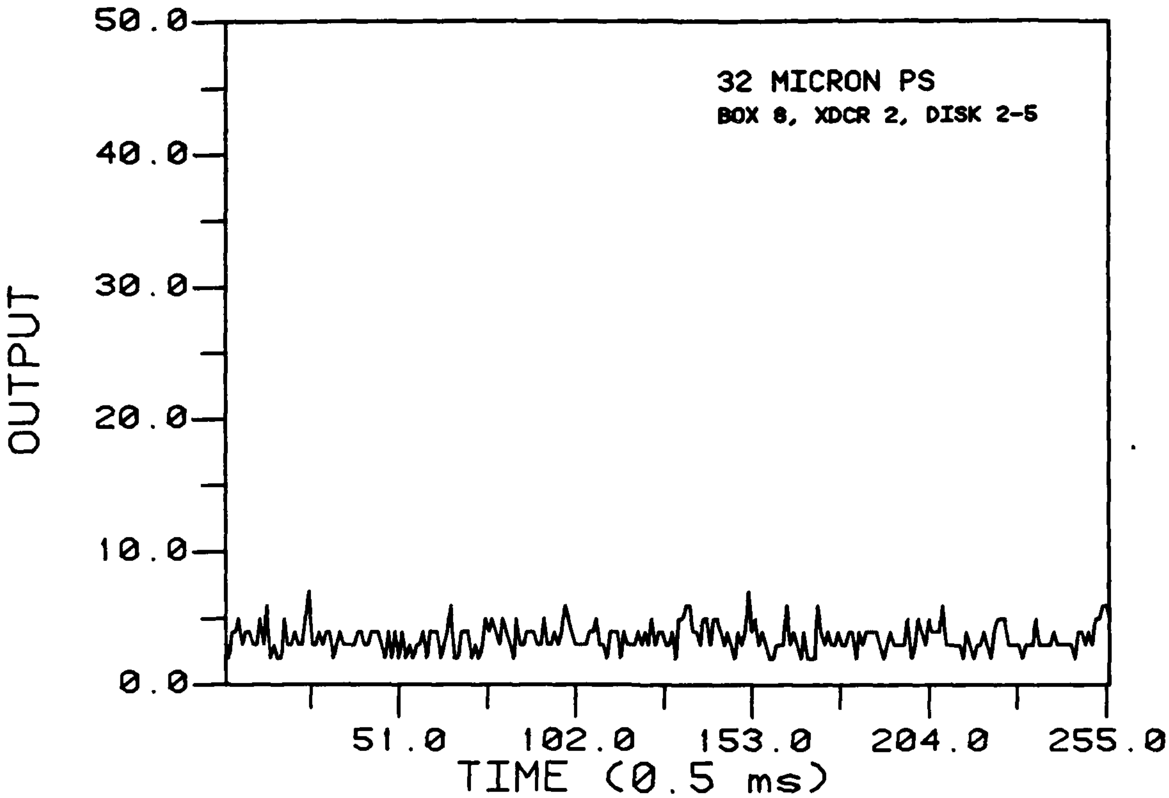
Results are shown two ways. The first as an actual output of the peak detector of which 256 of the total 16,384 samples are plotted. The second method illustrates selected frequency and accumulation plots.

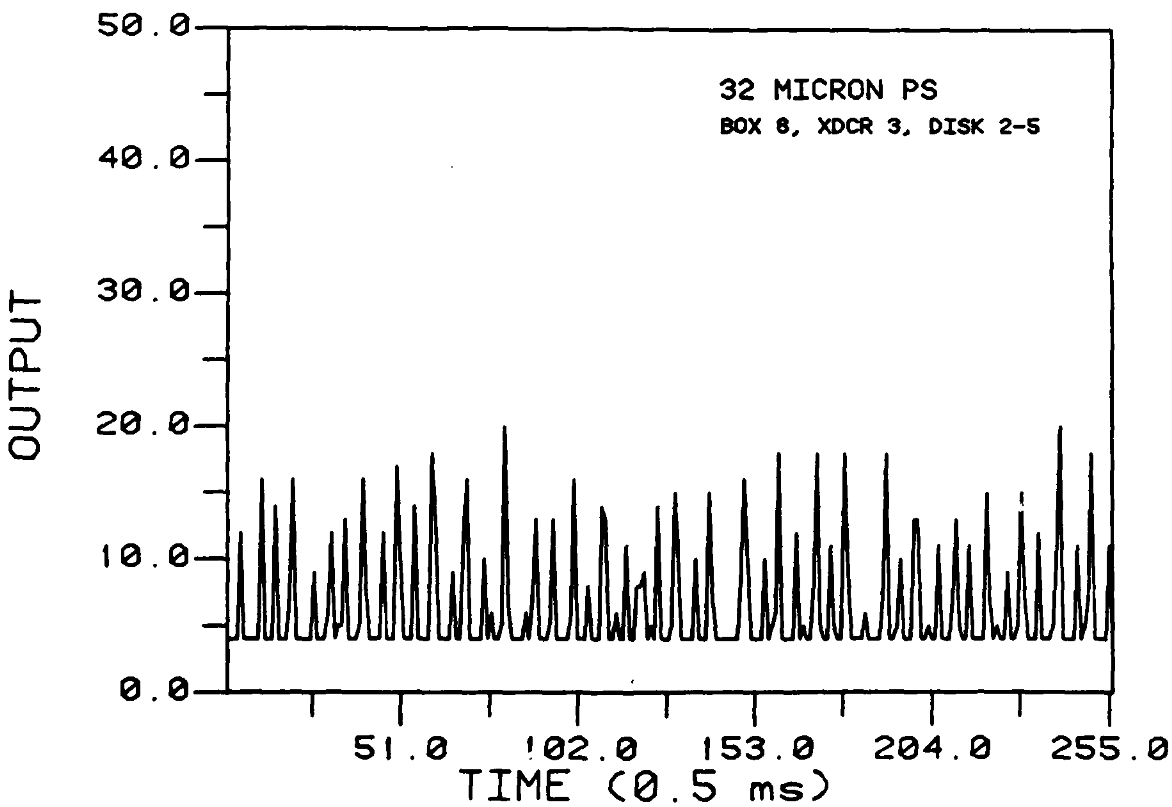

BASELINE
BOX 8, XDCR 2, DISK 1-1
OUTPUT
TIME (0.5 ms)
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0

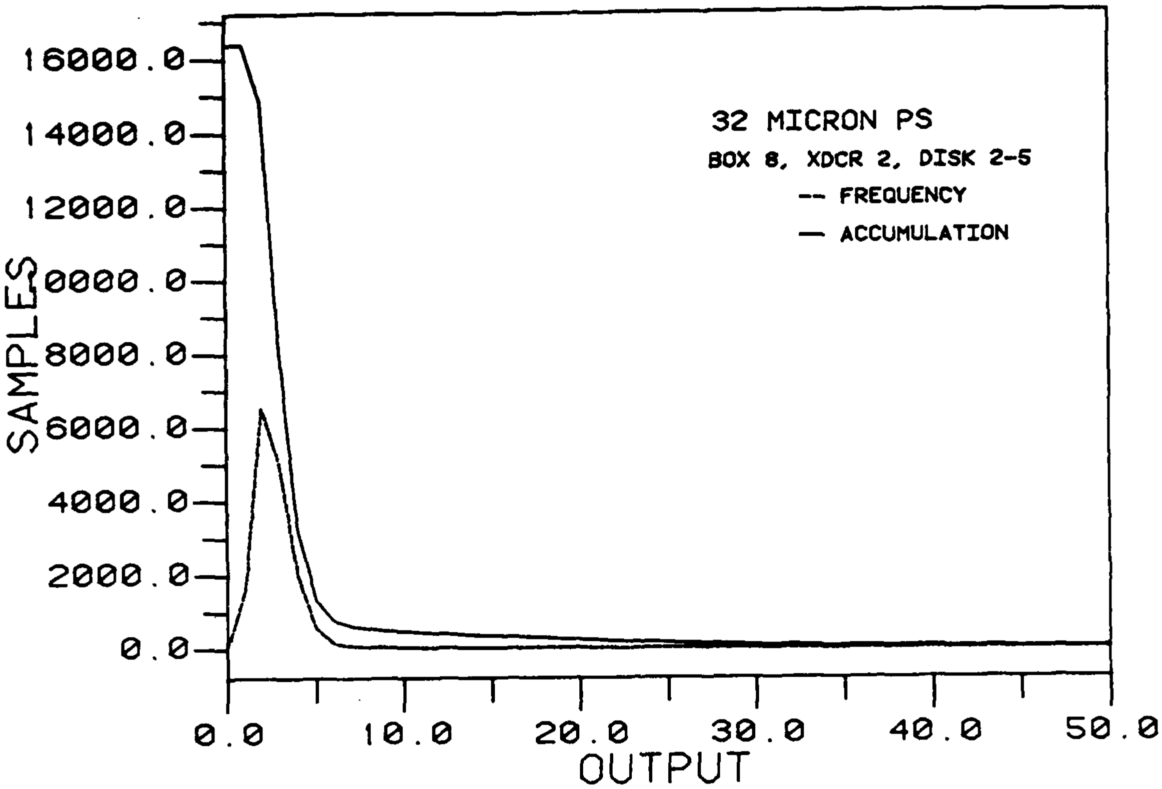

BASELINE
BOX 8, XDCR 3, DISK 1-1
OUTPUT
TIME (0.5 ms)
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0

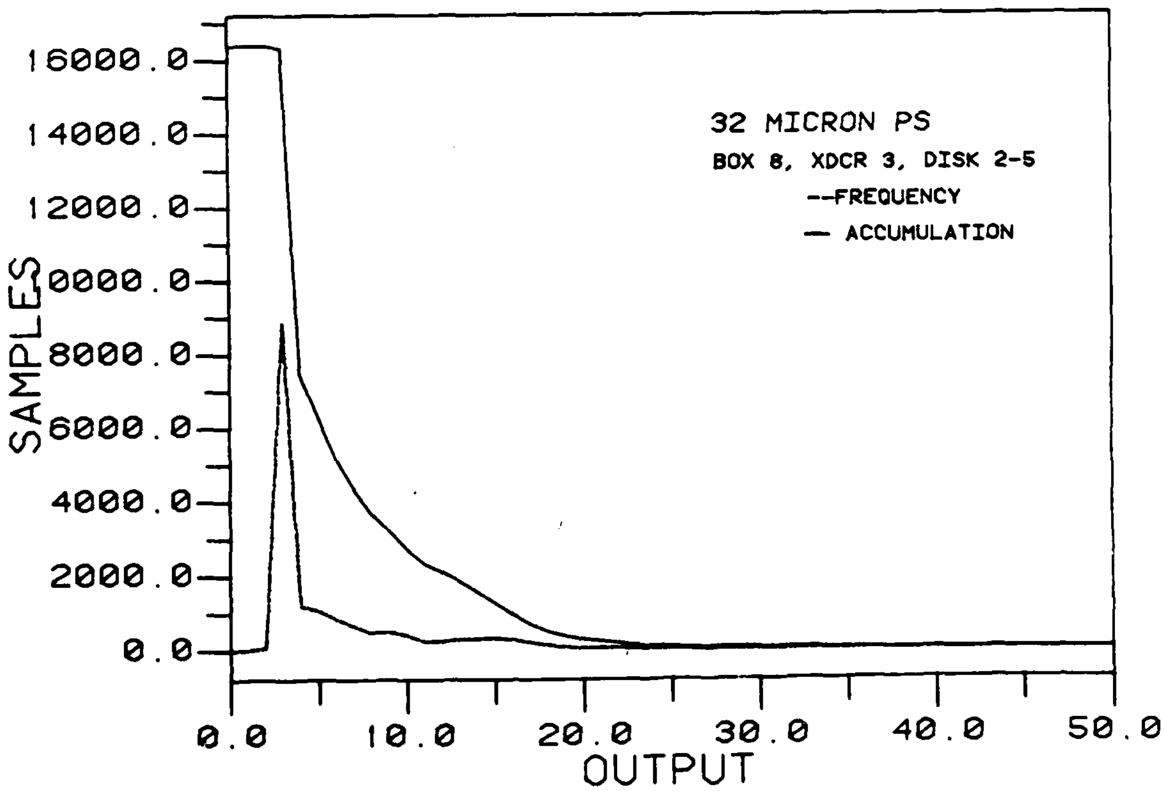

16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
BASELINE 32 MICRON PS
BOX 8, XDCR 2, DISK 1-1
-- FREQUENCY
— ACCUMULATION


16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
BASELINE 32 MICRON PS
BOX 8, XDCR 3, DISK 1-1
-- FREQUENCY
— ACCUMULATION


32 MICRON PS
BOX 8, XDCR 2, DISK 2-5
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

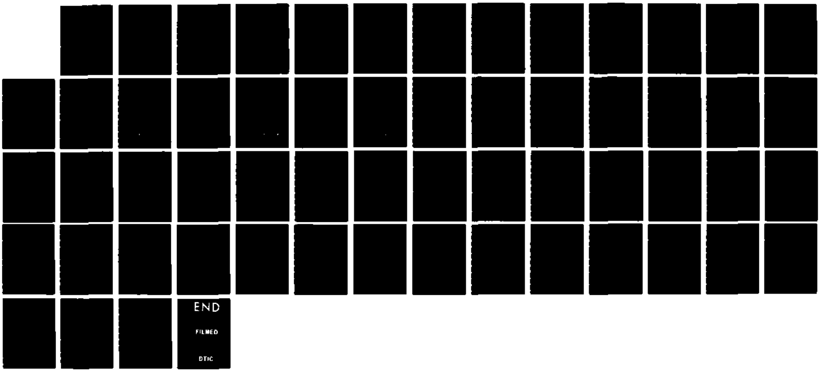

32 MICRON PS
BOX 8, XDCR 3, DISK 2-5
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

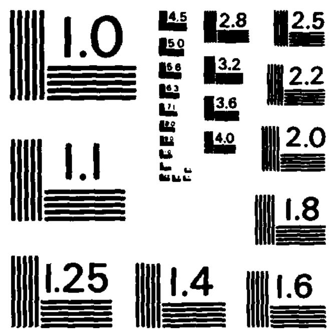

16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
32 MICRON PS
BOX 8, XDCR 2, DISK 2-5
-- FREQUENCY
— ACCUMULATION

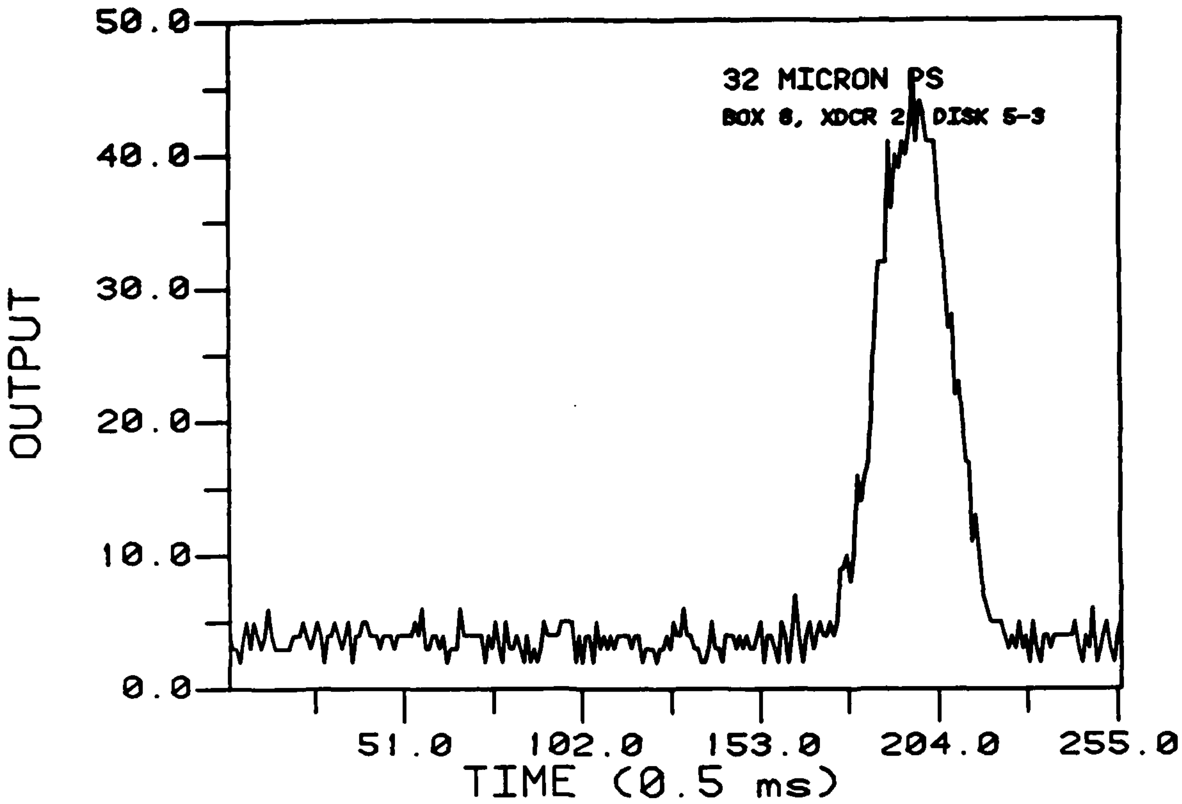

16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
32 MICRON PS
BOX 8, XDCR 3, DISK 2-5
--FREQUENCY
— ACCUMULATION

AD-A158 989 ULTRASONIC MEASUREMENT OF PARTICLES IN A VISCOUS FLUID (U) MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN ENGINEERING L E OSLUND FEB 85 N66314-70-A-0073 2/2

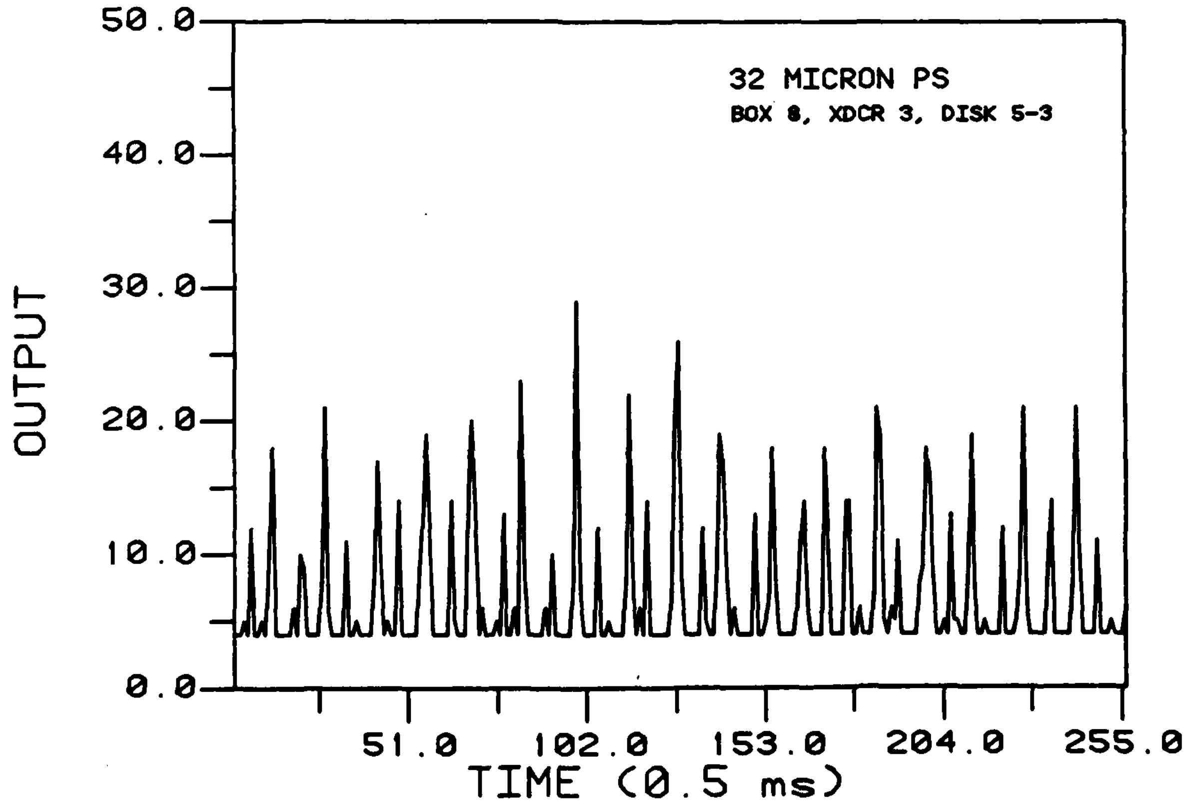
UNCLASSIFIED F/G 17/1 NL



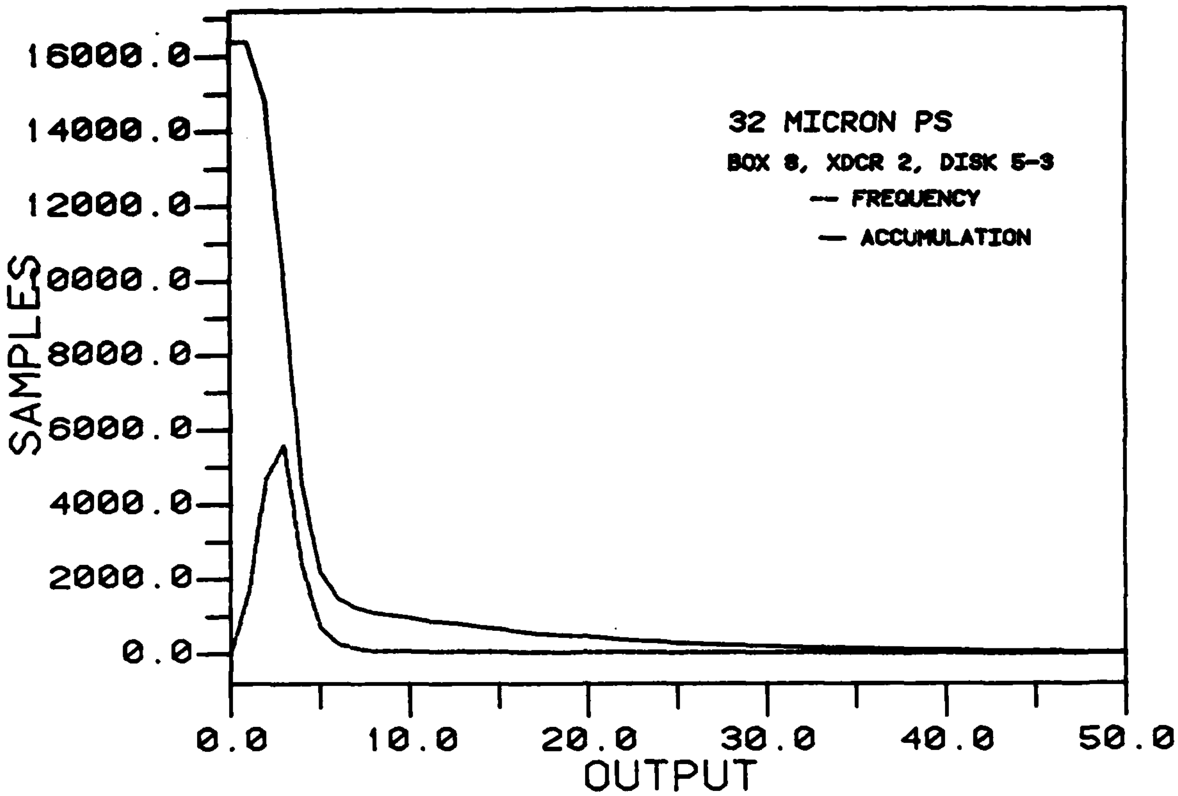

1.0
4.5
5.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

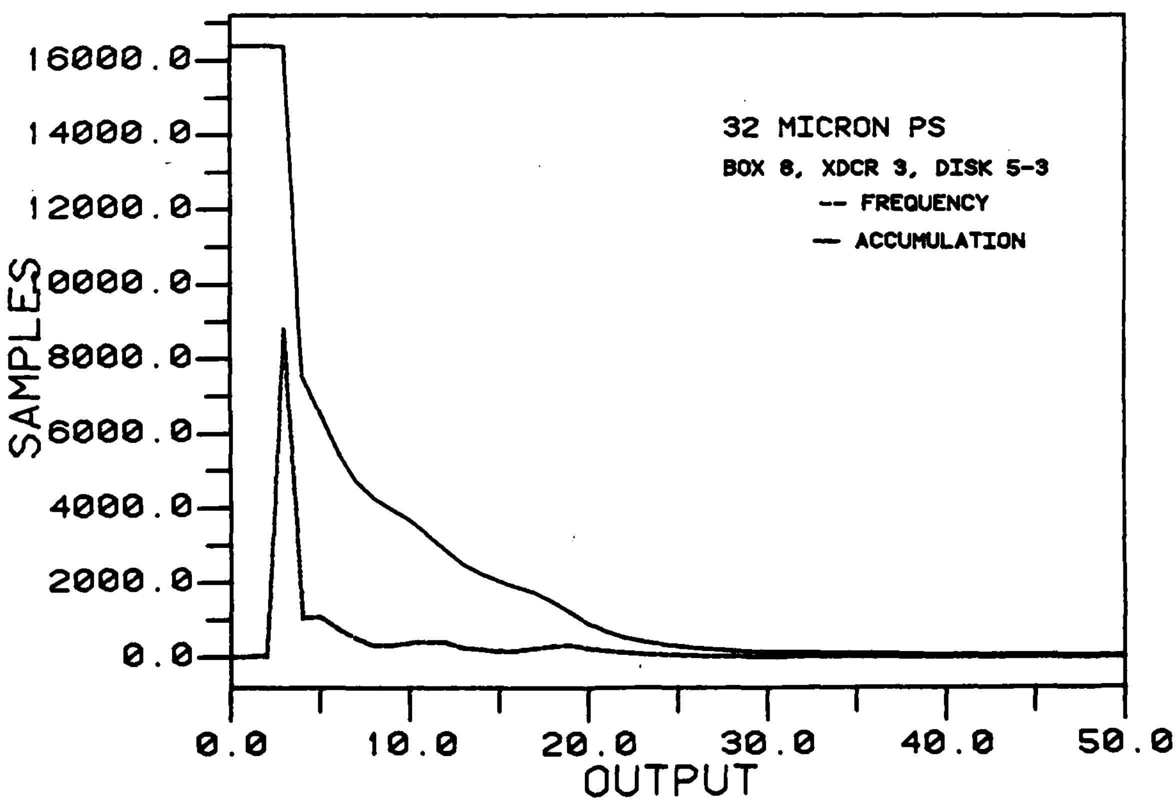


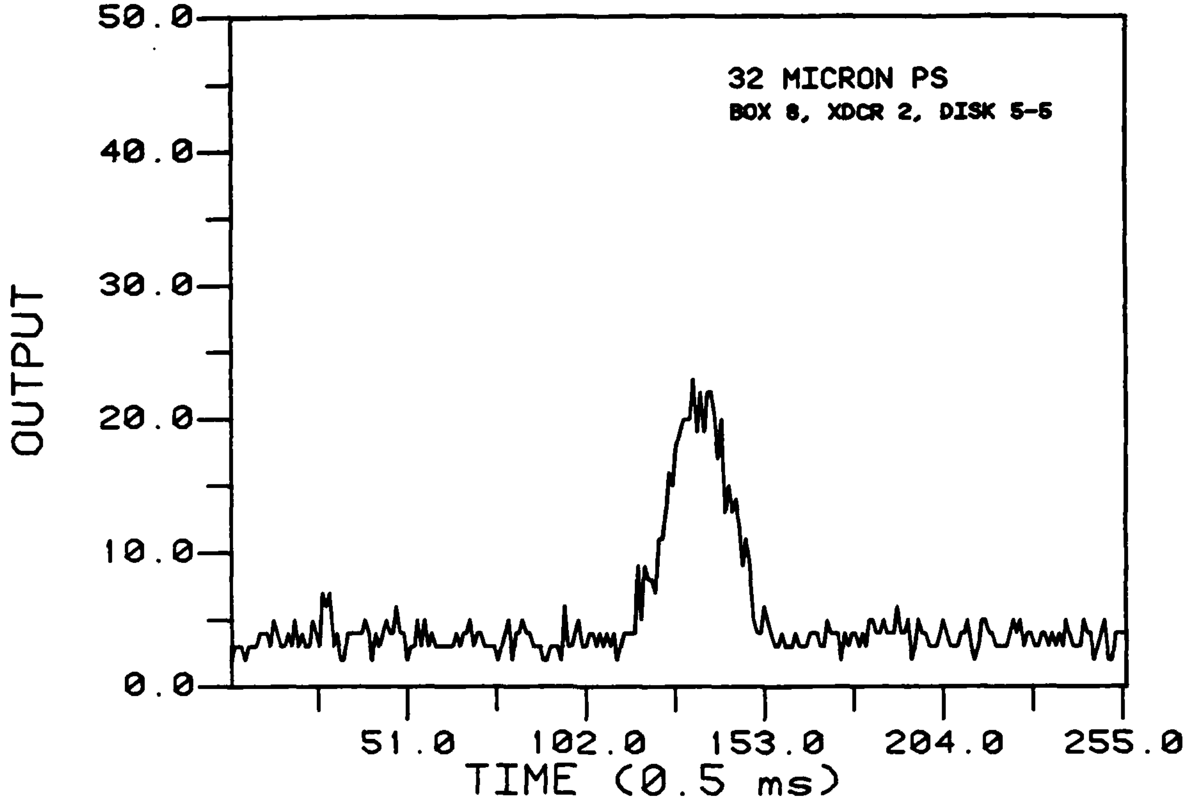
32 MICRON PS
BOX 8, XDCR 2, DISK 5-3
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



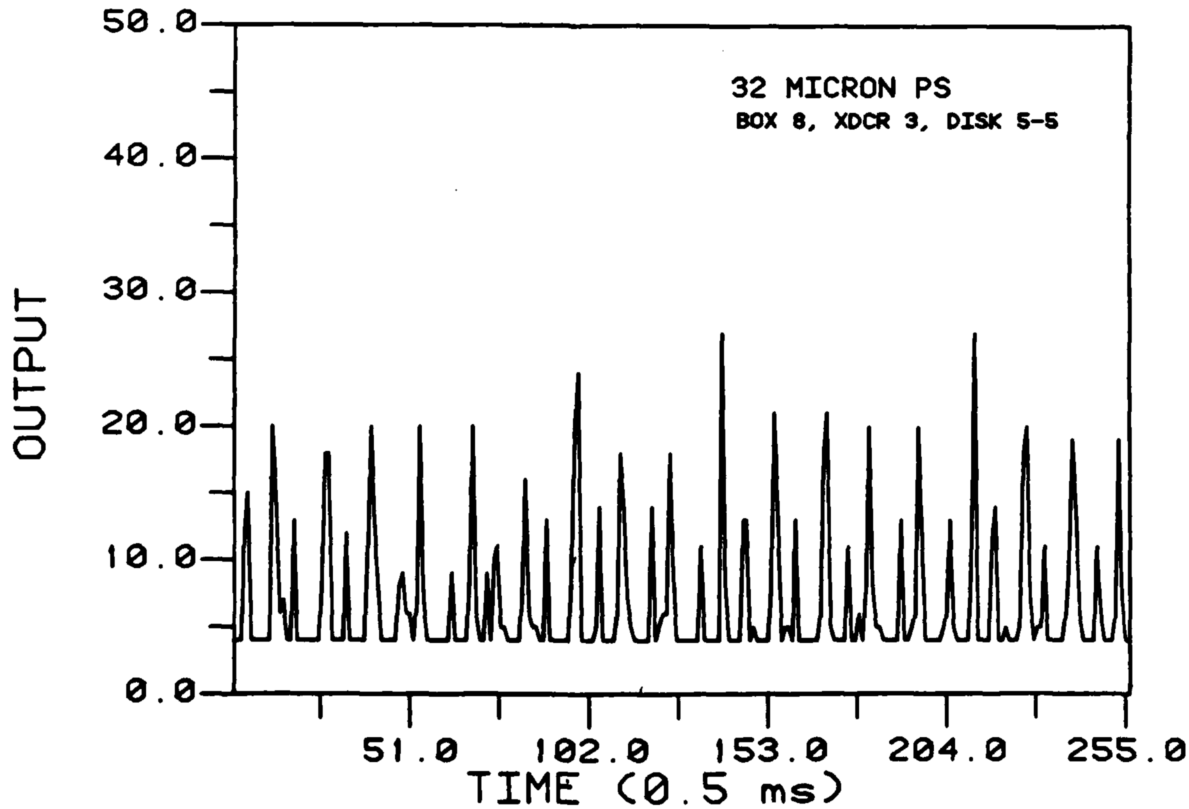
32 MICRON PS
BOX 8, XDCR 3, DISK 5-3
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


32 MICRON PS
BOX 8, XDCR 2, DISK 5-3
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

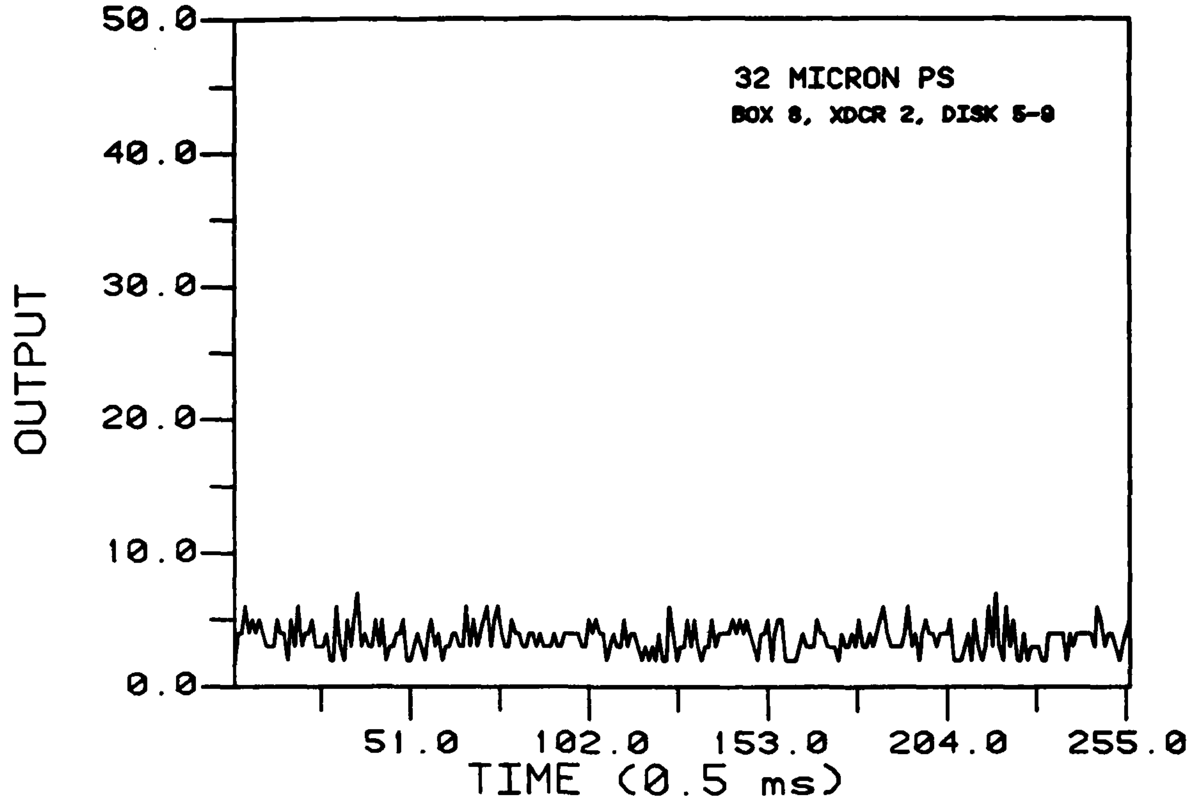

32 MICRON PS
BOX 8, XDCR 3, DISK 5-3
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

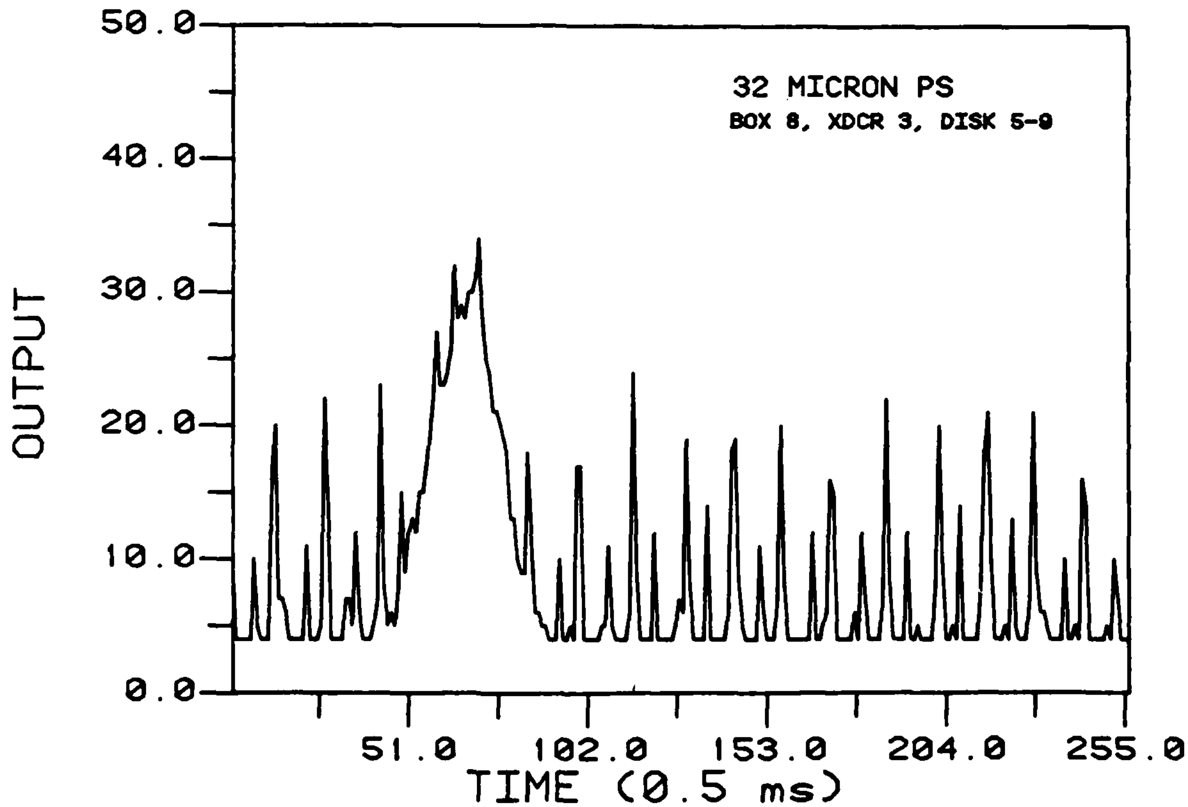


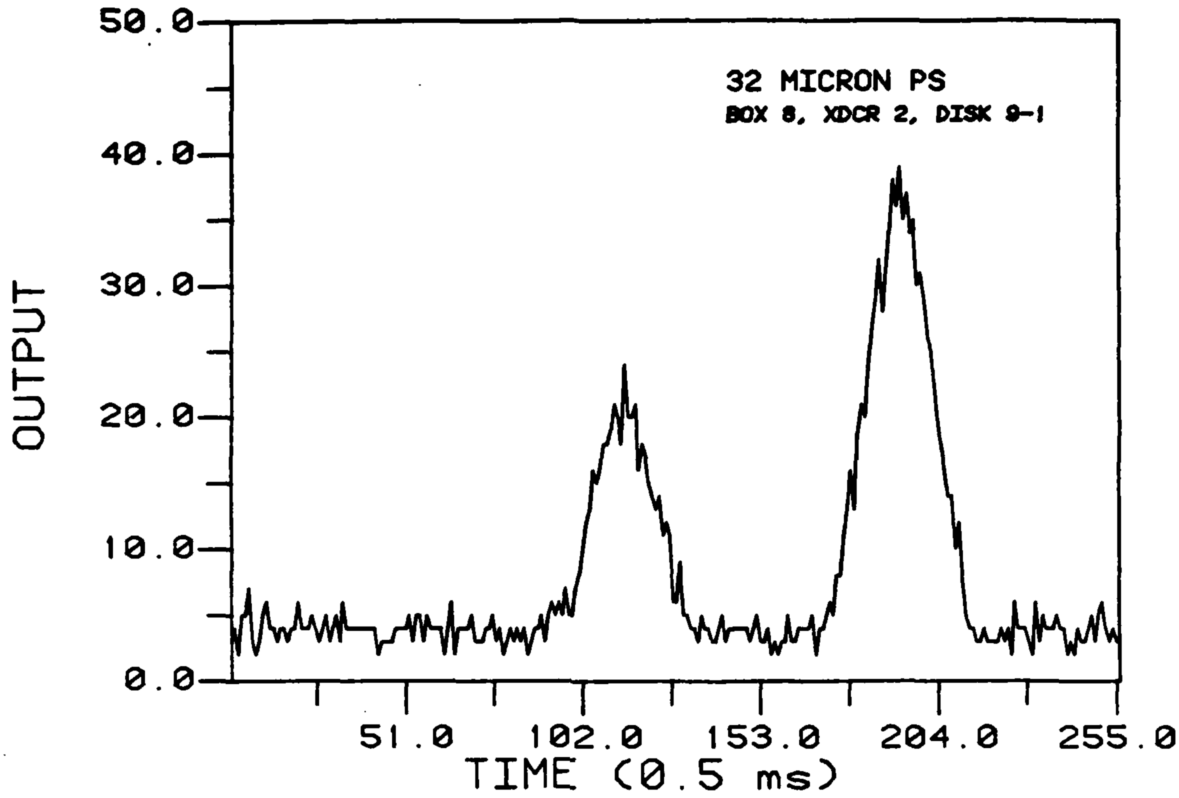
32 MICRON PS
BOX 8, XDCR 2, DISK 5-5
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

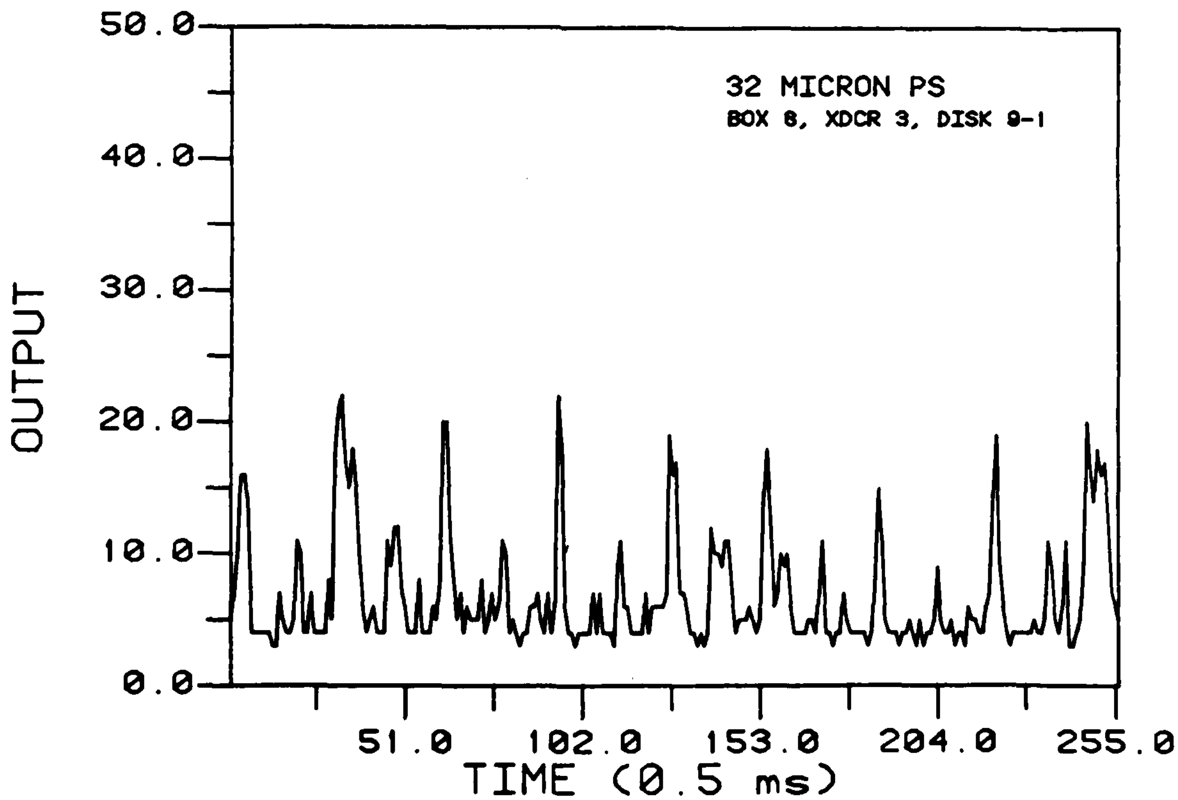


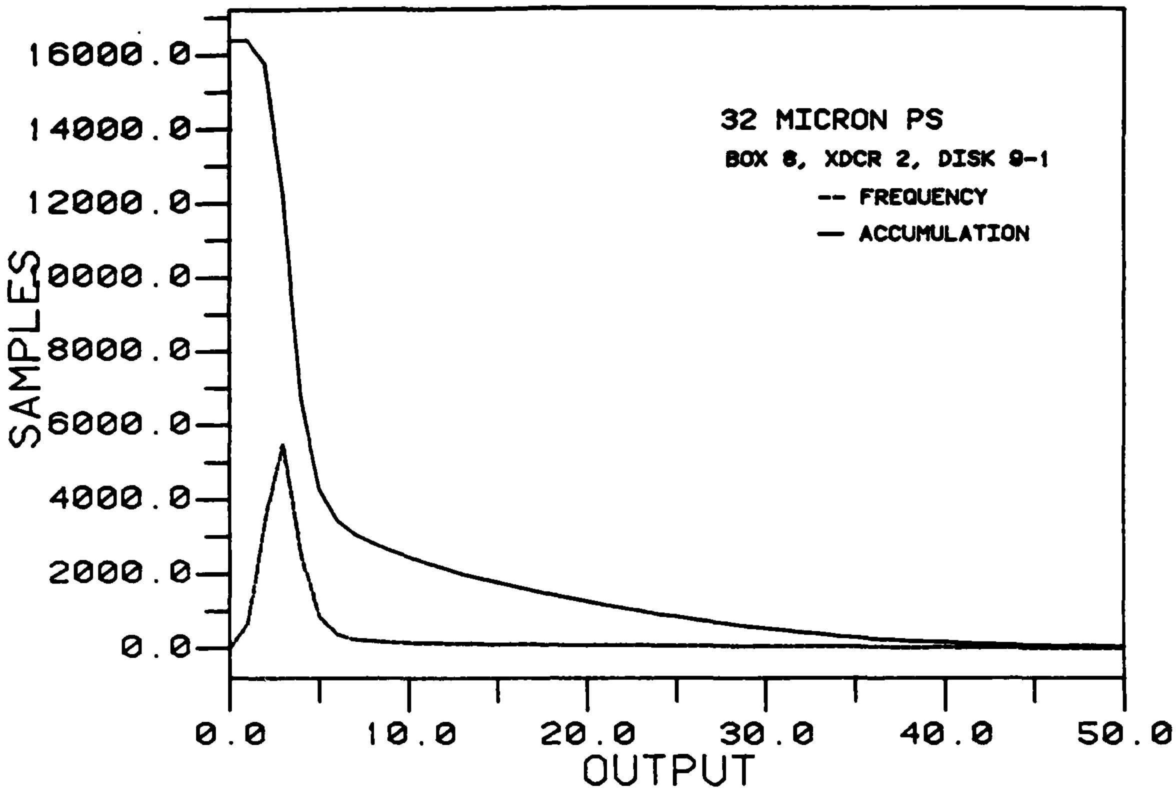
32 MICRON PS
BOX 8, XDCR 3, DISK 5-5
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


32 MICRON PS
BOX 8, XDCR 2, DISK 5-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

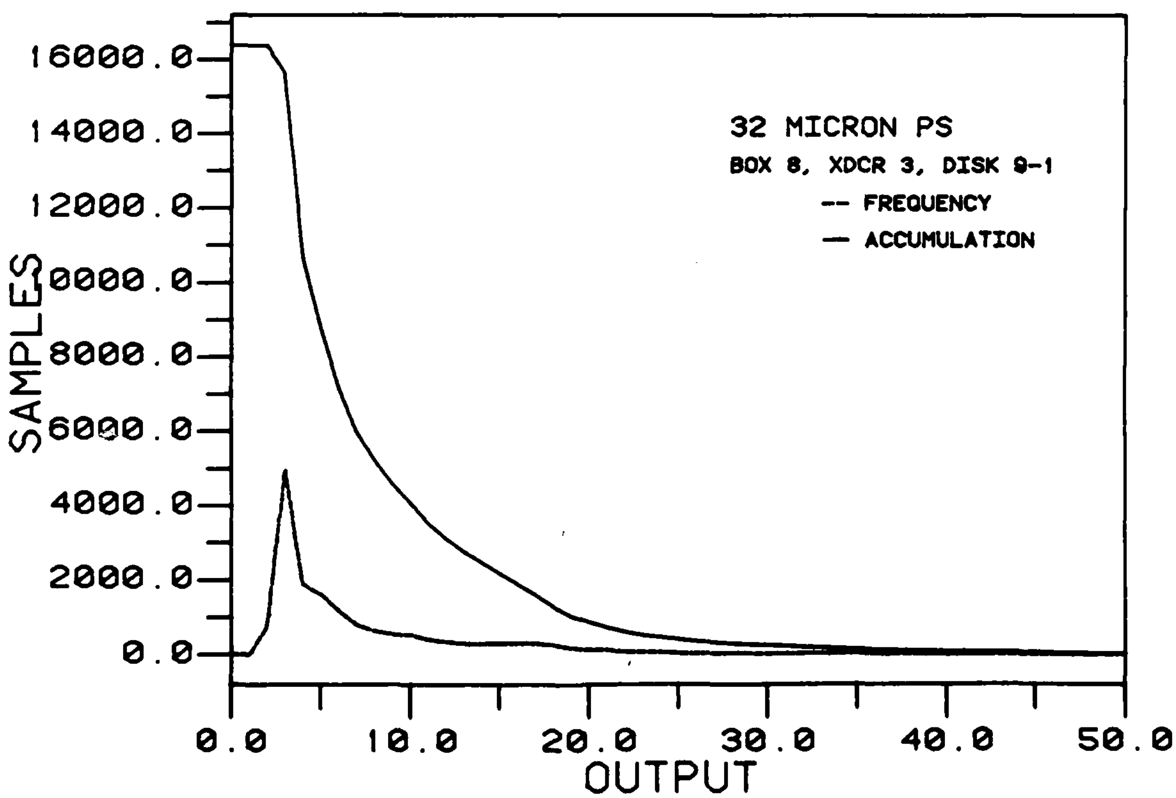

32 MICRON PS
BOX 8, XDCR 3, DISK 5-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


32 MICRON PS
BOX 8, XDCR 2, DISK 9-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

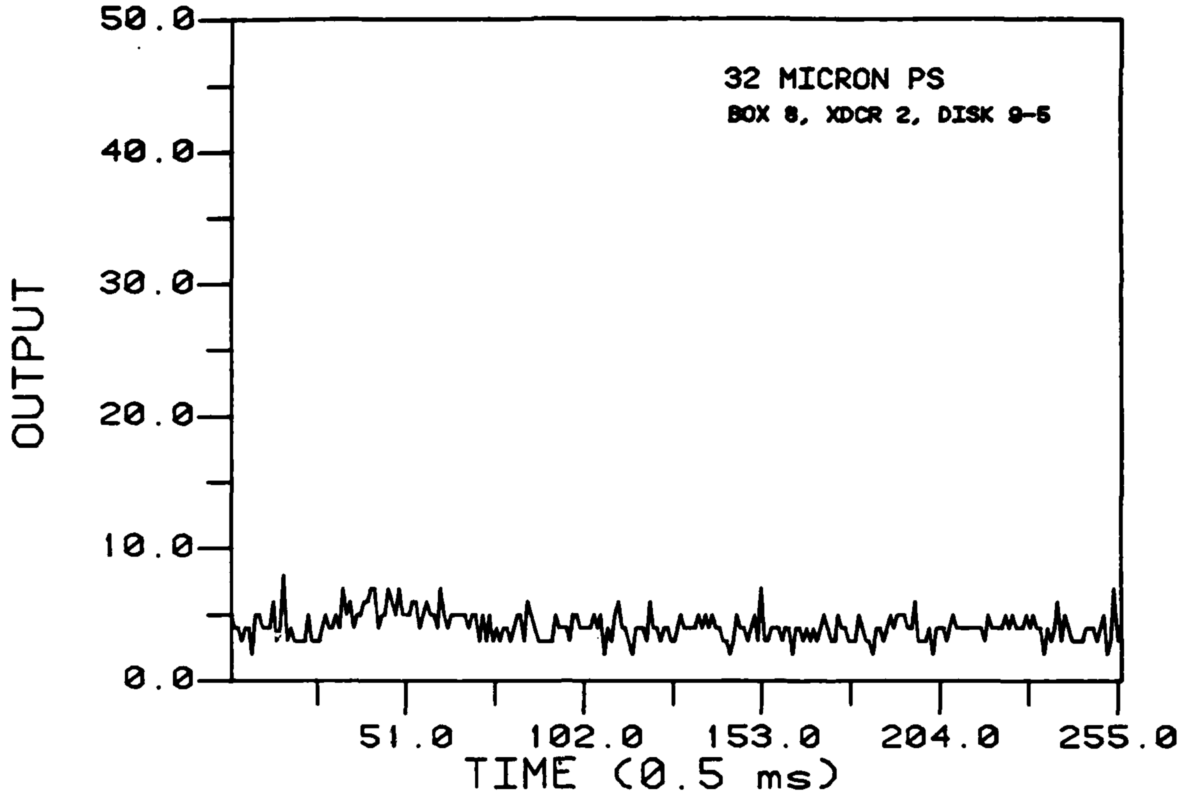

32 MICRON PS
BOX 8, XDCR 3, DISK 9-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

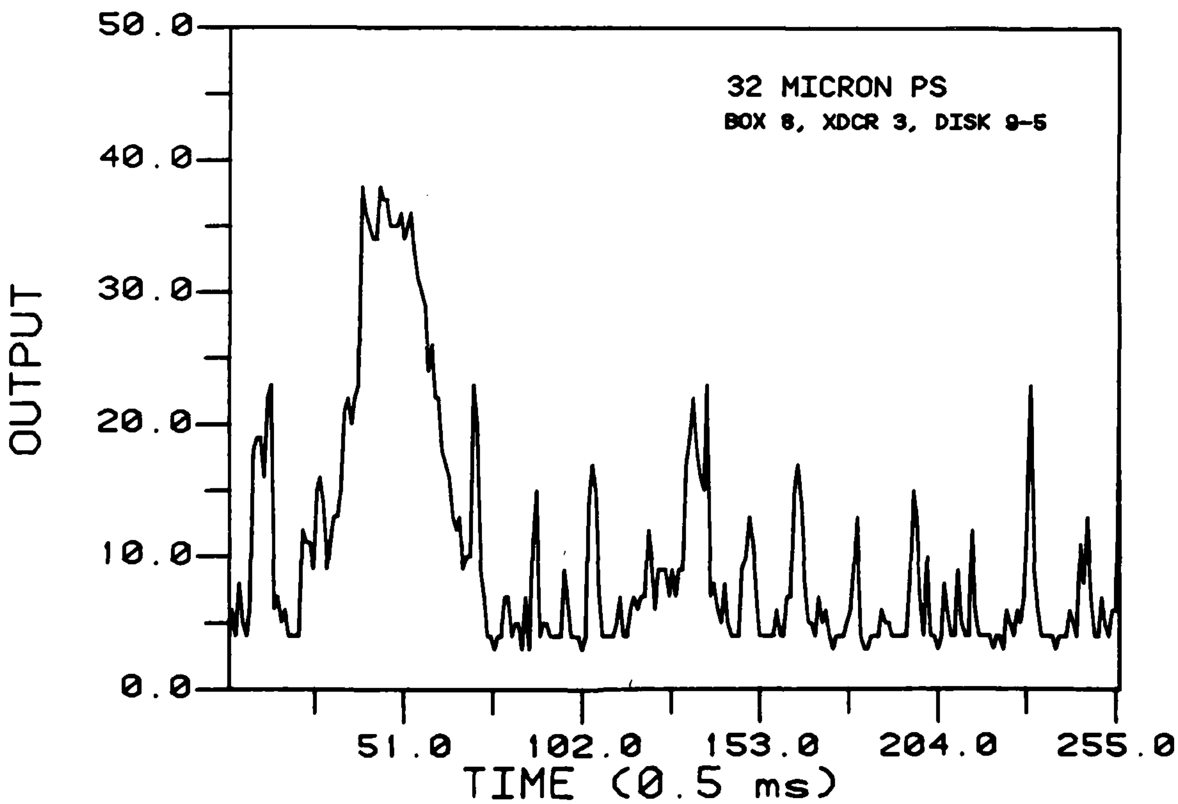


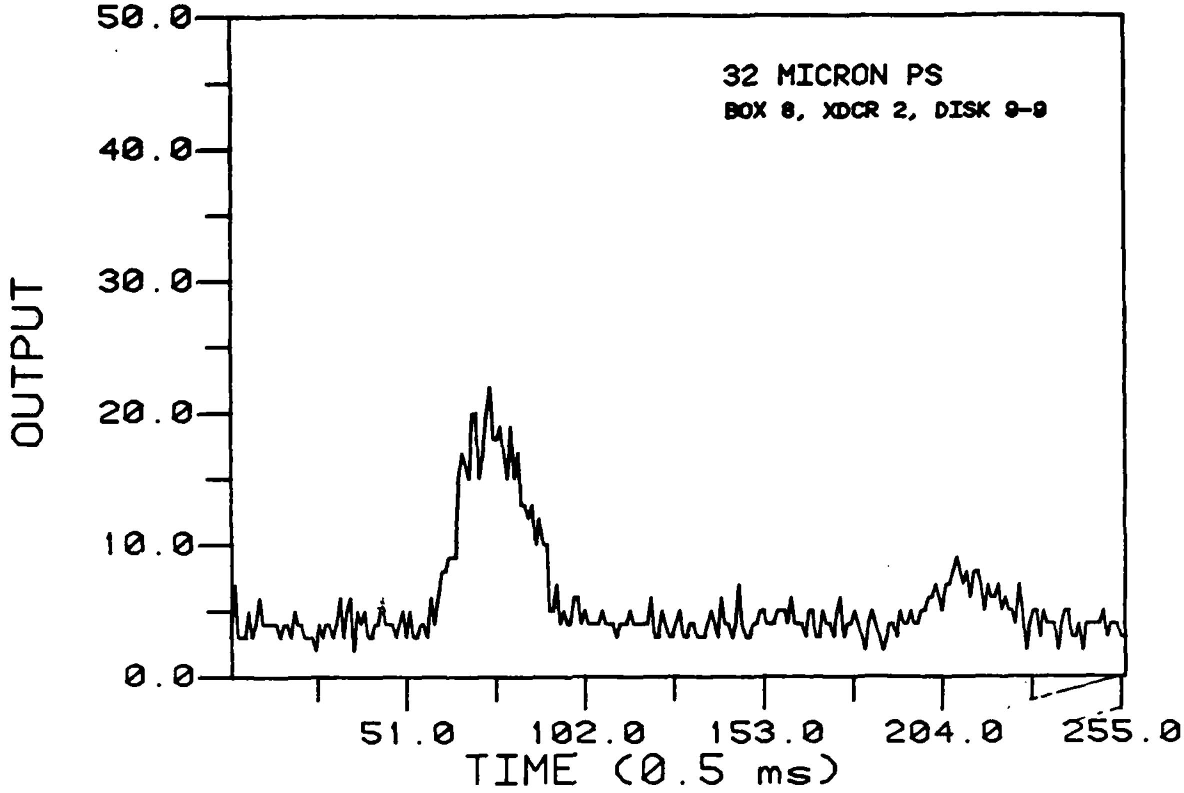
32 MICRON PS
BOX 8, XDCR 2, DISK 9-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
OUTPUT



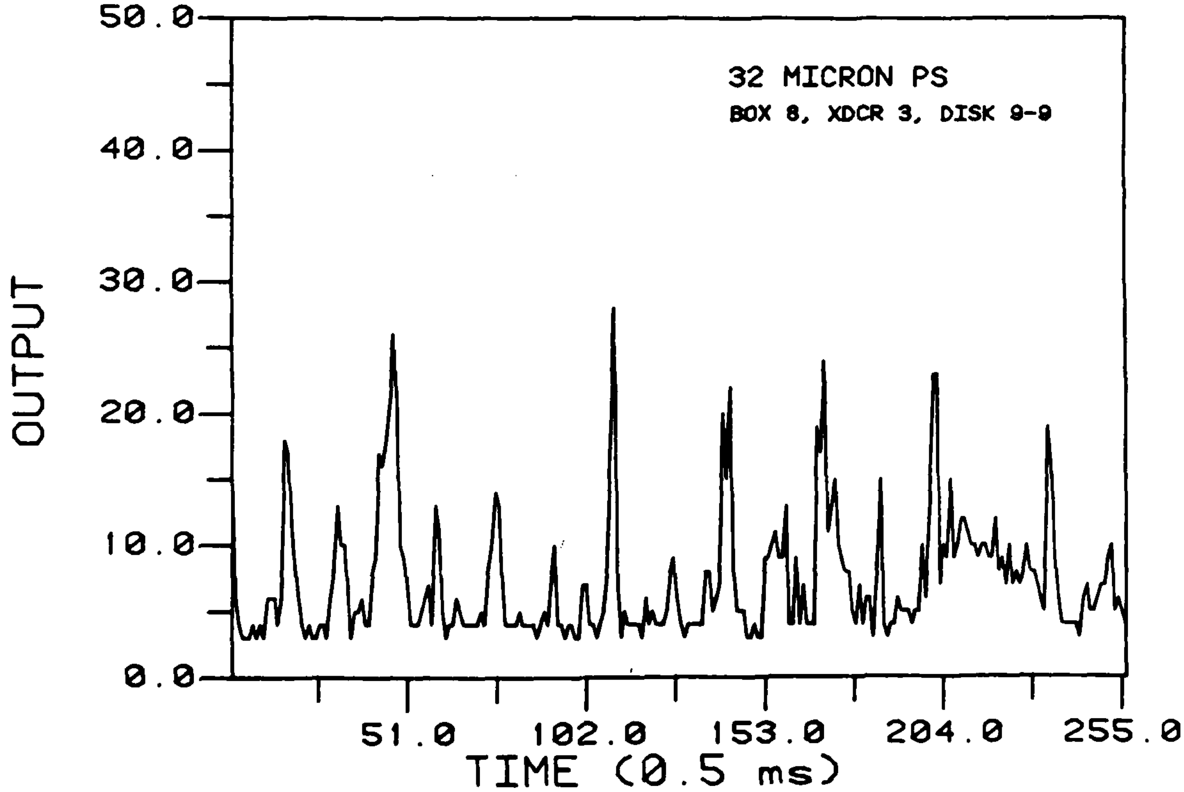
32 MICRON PS
BOX 8, XDCR 3, DISK 9-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
OUTPUT


32 MICRON PS
BOX 8, XDCR 2, DISK 9-5
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

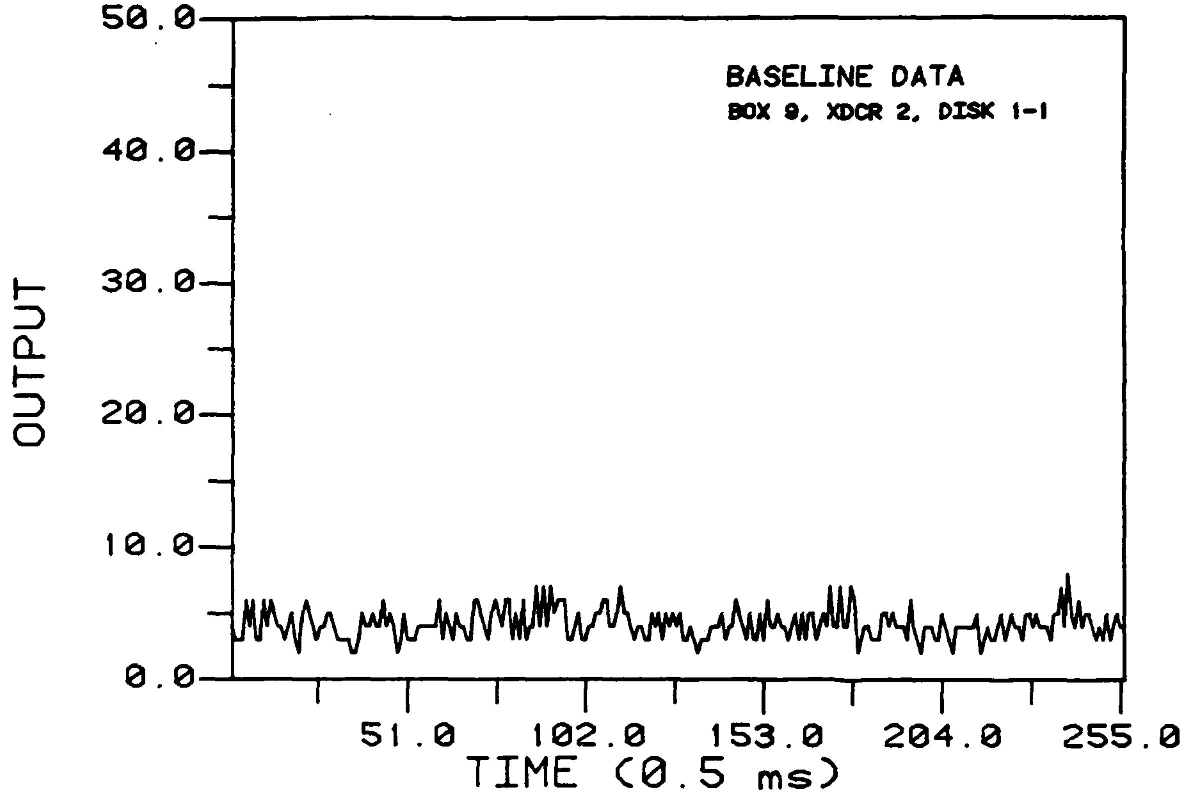

32 MICRON PS
BOX 8, XDCR 3, DISK 9-5
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



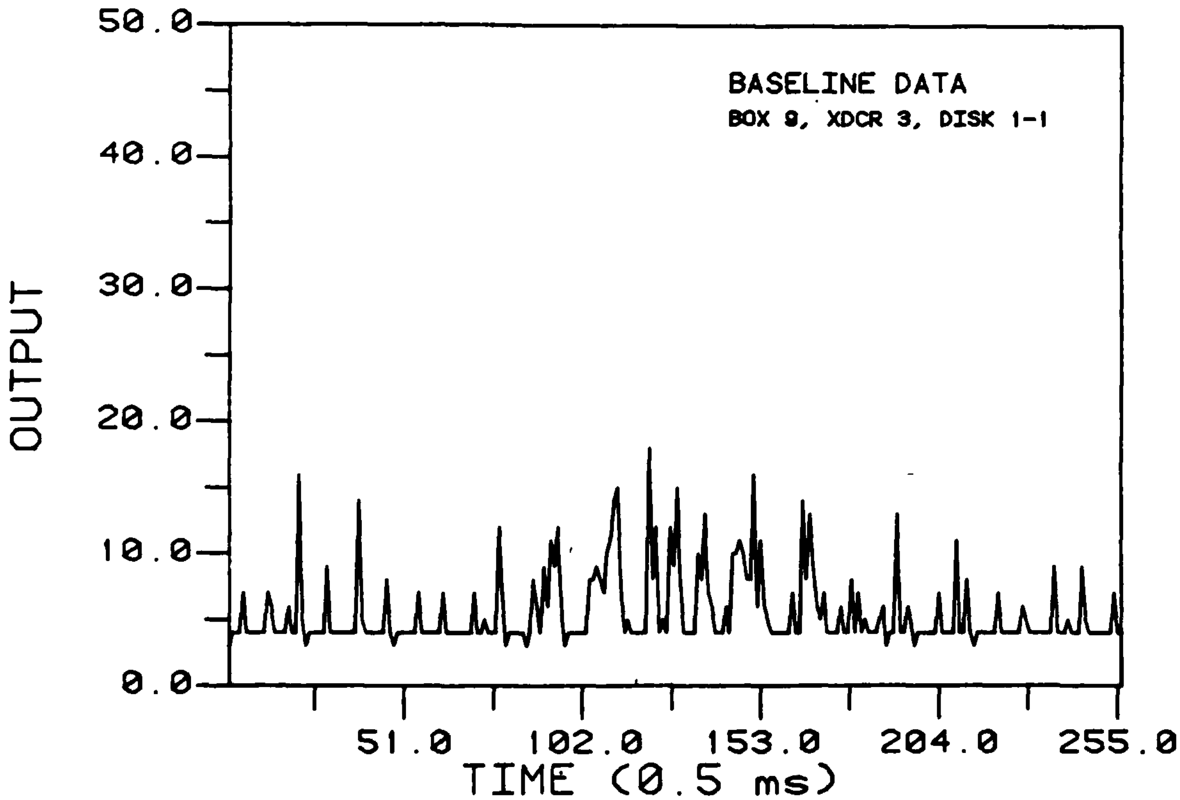
32 MICRON PS
BOX 8, XDCR 2, DISK 9-9
OUTPUT
TIME (0.5 ms)



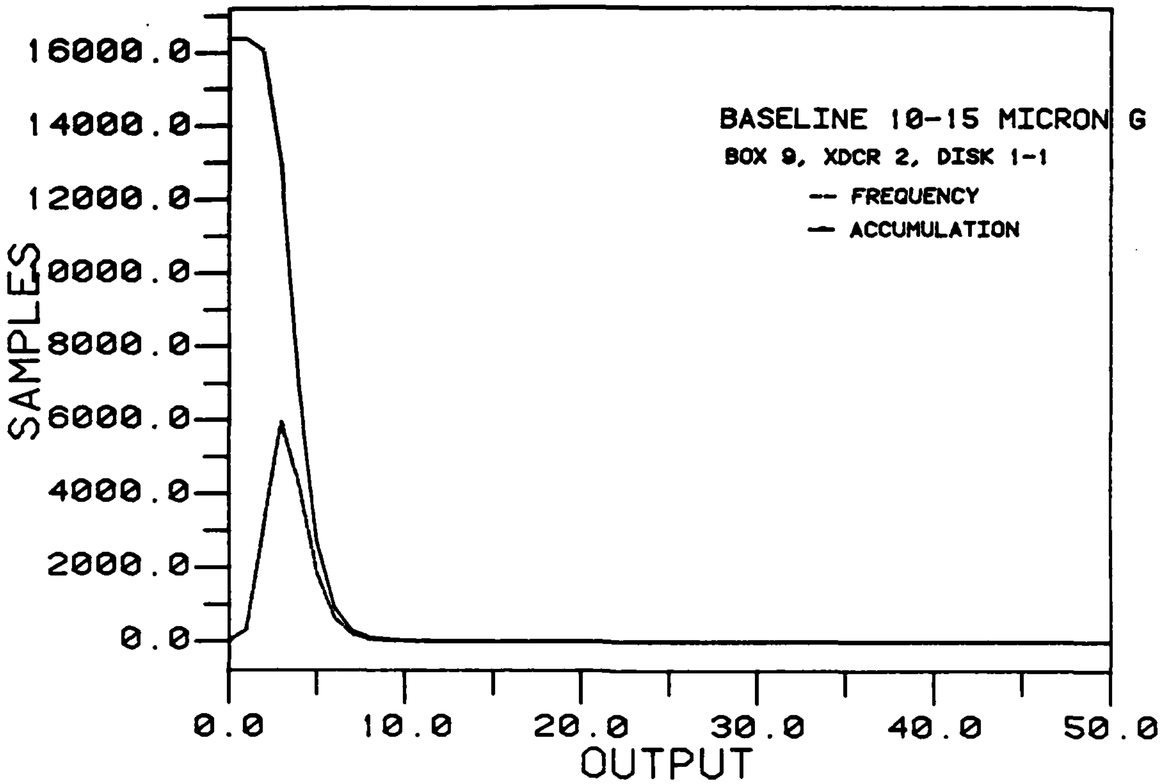
32 MICRON PS
BOX 8, XDCR 3, DISK 9-9
OUTPUT
TIME (0.5 ms)

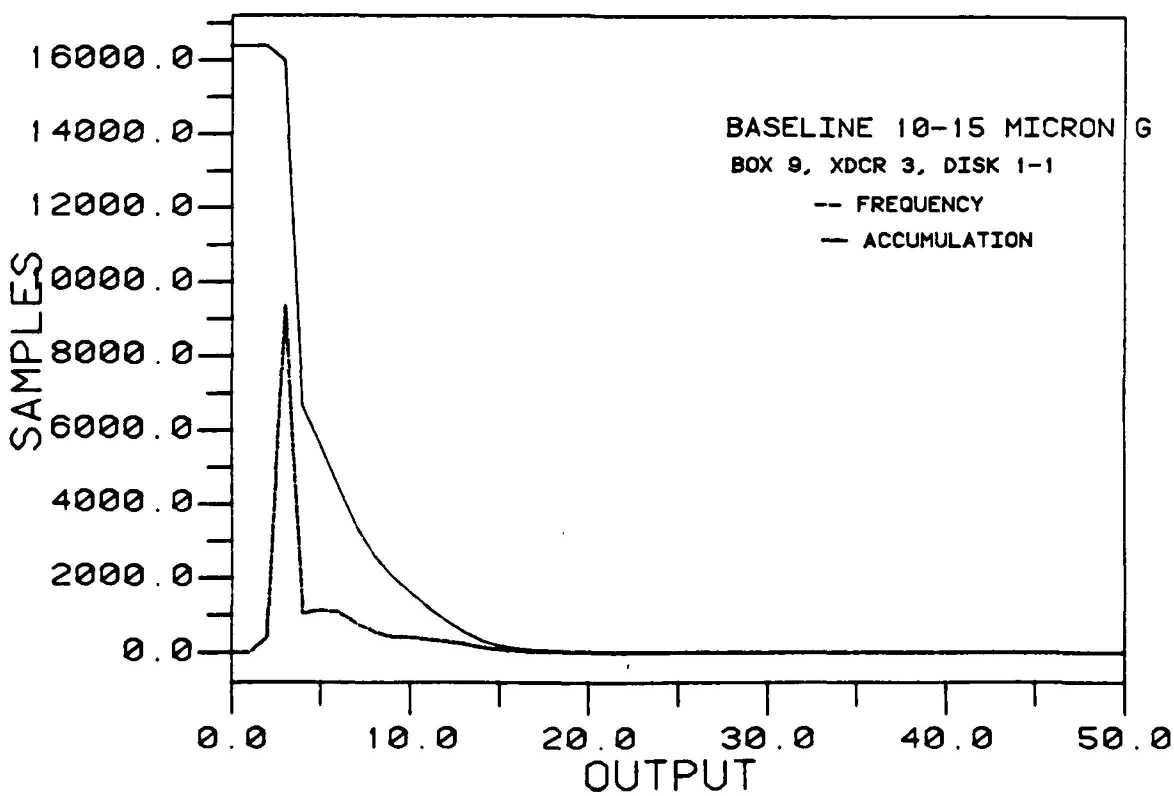


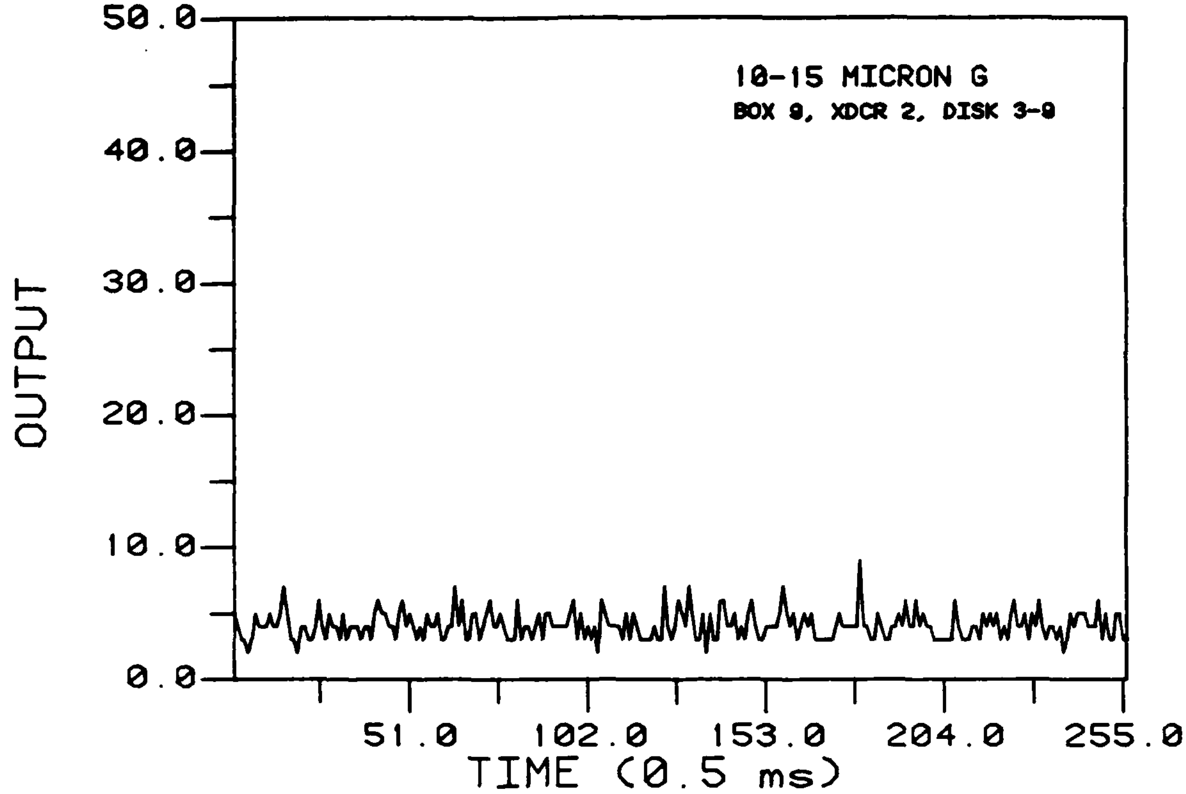
BASELINE DATA
BOX 9, XDCR 2, DISK 1-1
50.0
40.0
30.0
20.0
10.0
0.0
OUTPUT
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

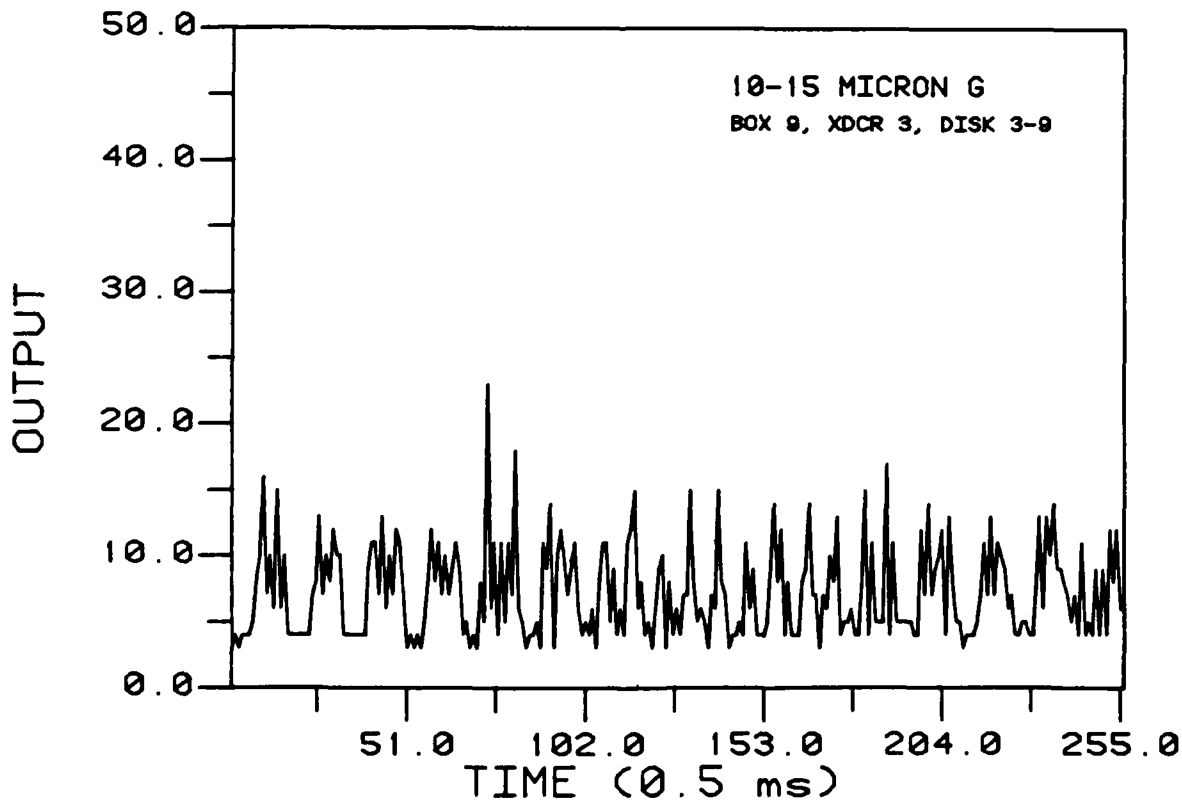


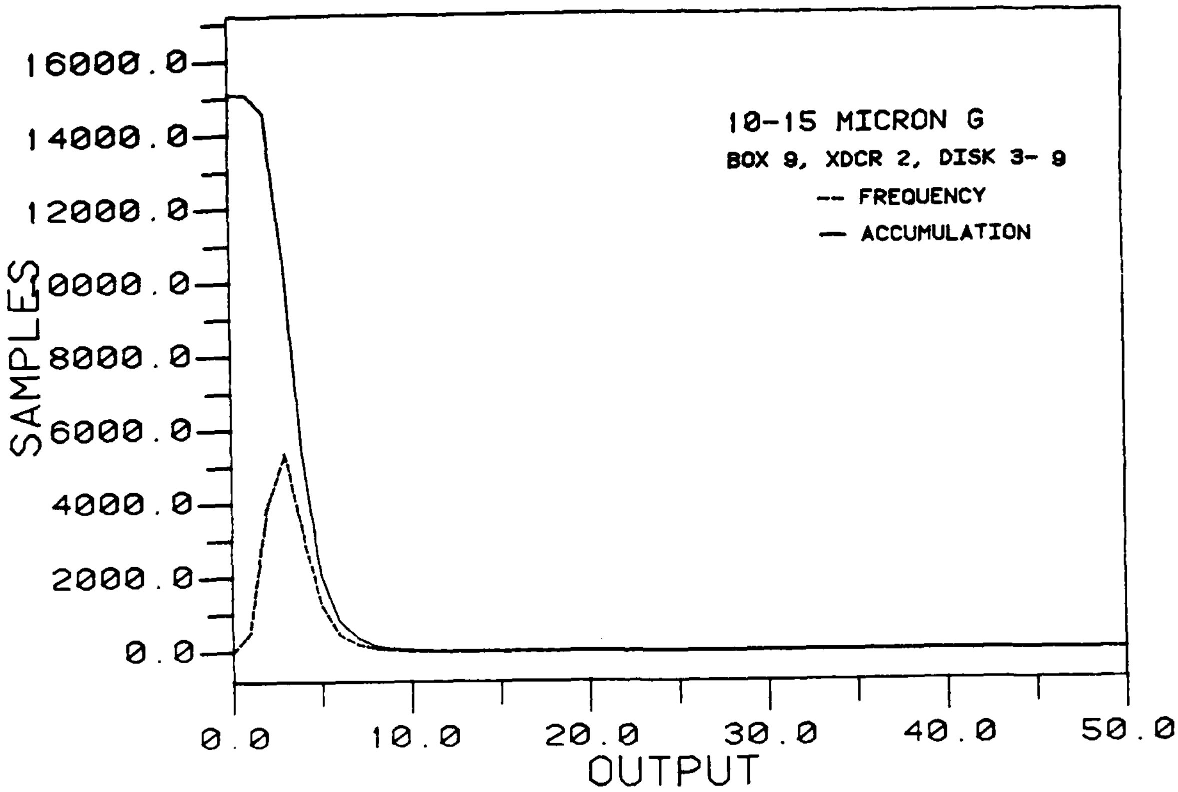
BASELINE DATA
BOX 9, XDCR 3, DISK 1-1
50.0
40.0
30.0
20.0
10.0
0.0
OUTPUT
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

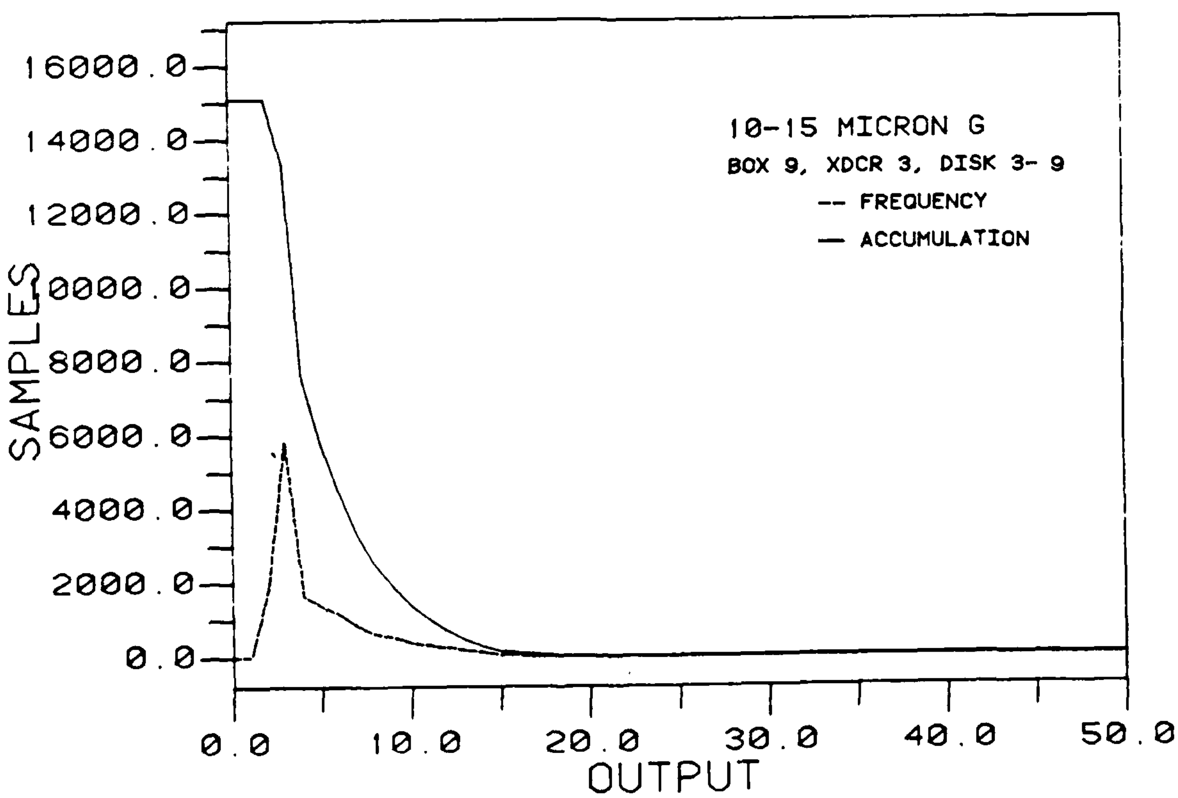

BASELINE 10-15 MICRON G
BOX 9, XDCR 2, DISK 1-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

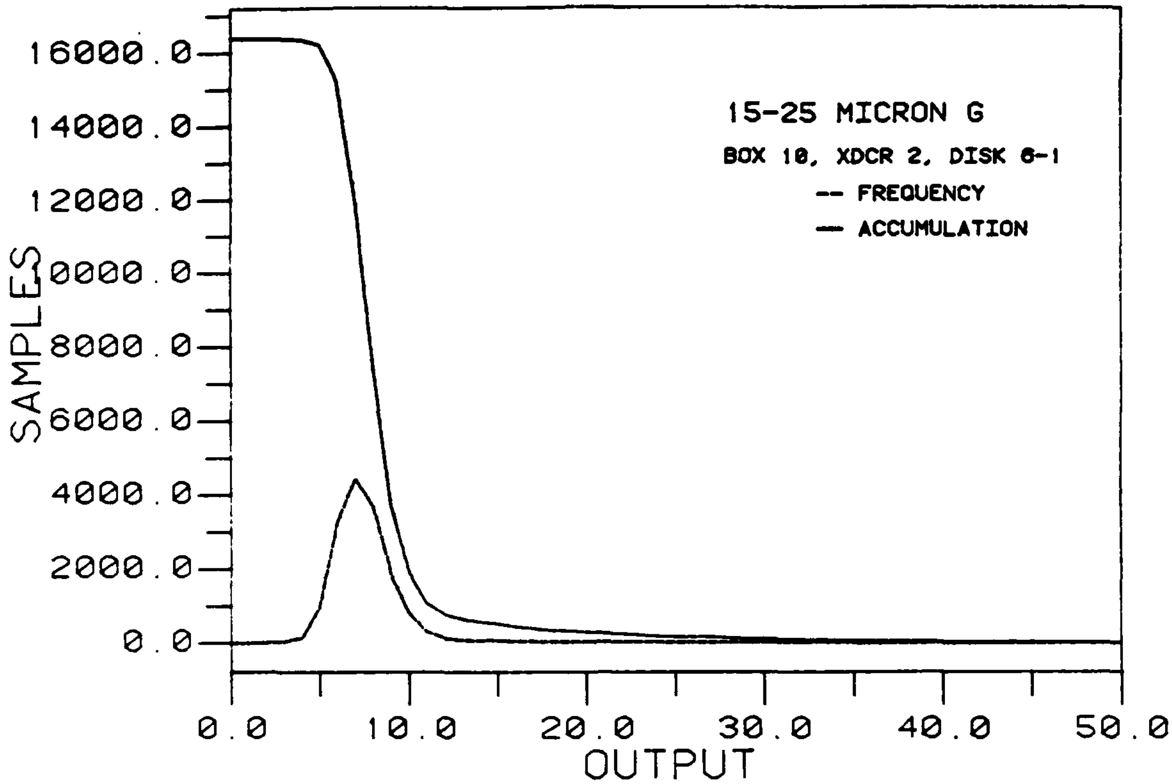

BASELINE 10-15 MICRON G
BOX 9, XDCR 3, DISK 1-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

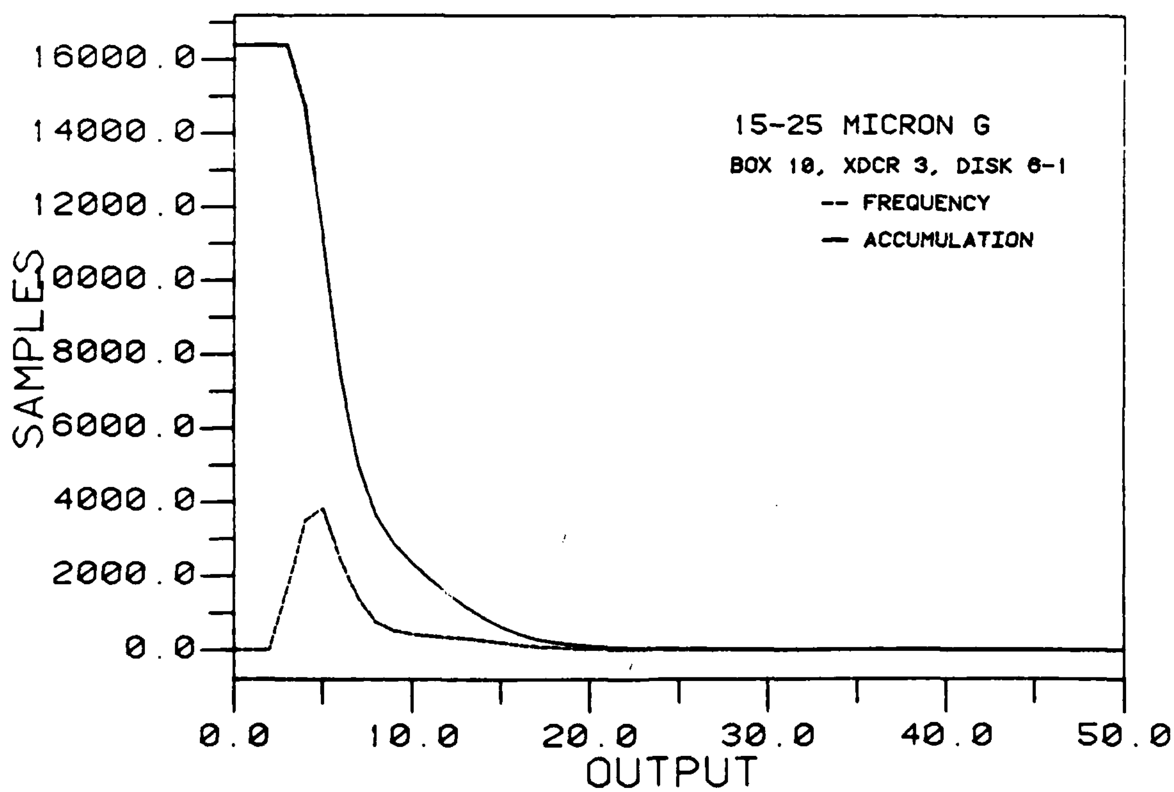

10-15 MICRON G
BOX 9, XDCR 2, DISK 3-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

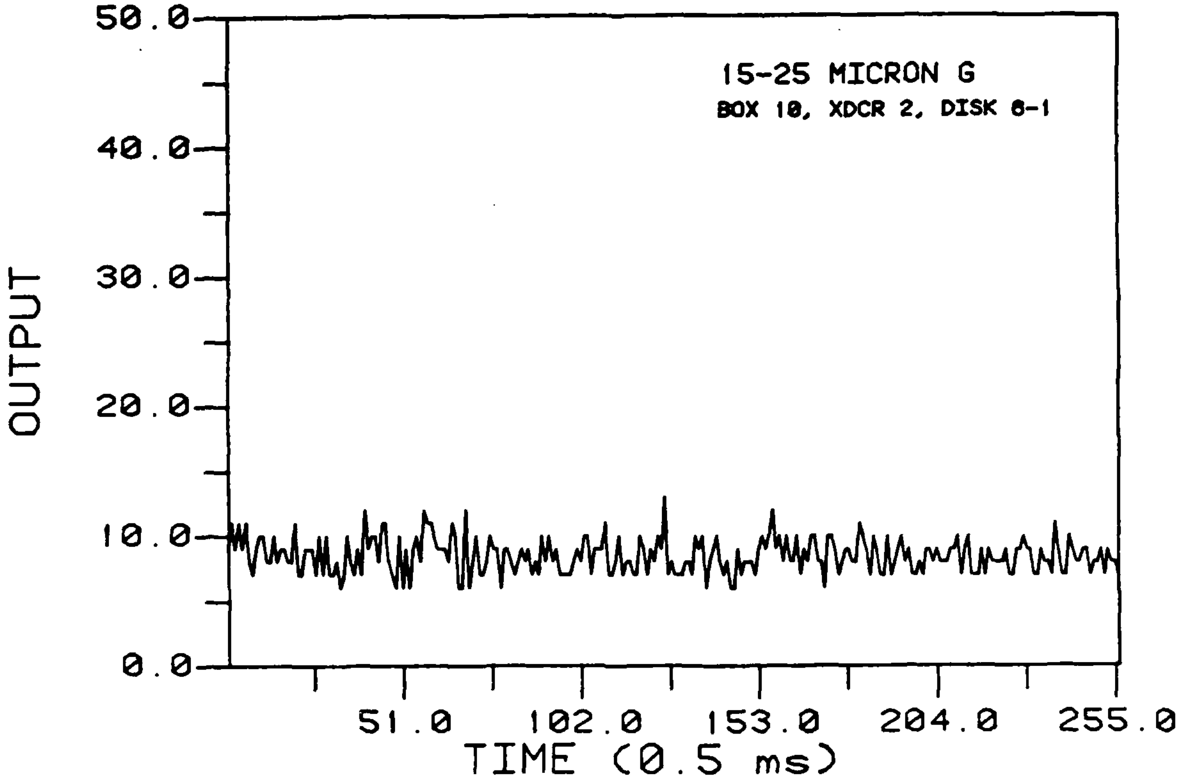

10-15 MICRON G
BOX 9, XDCR 3, DISK 3-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

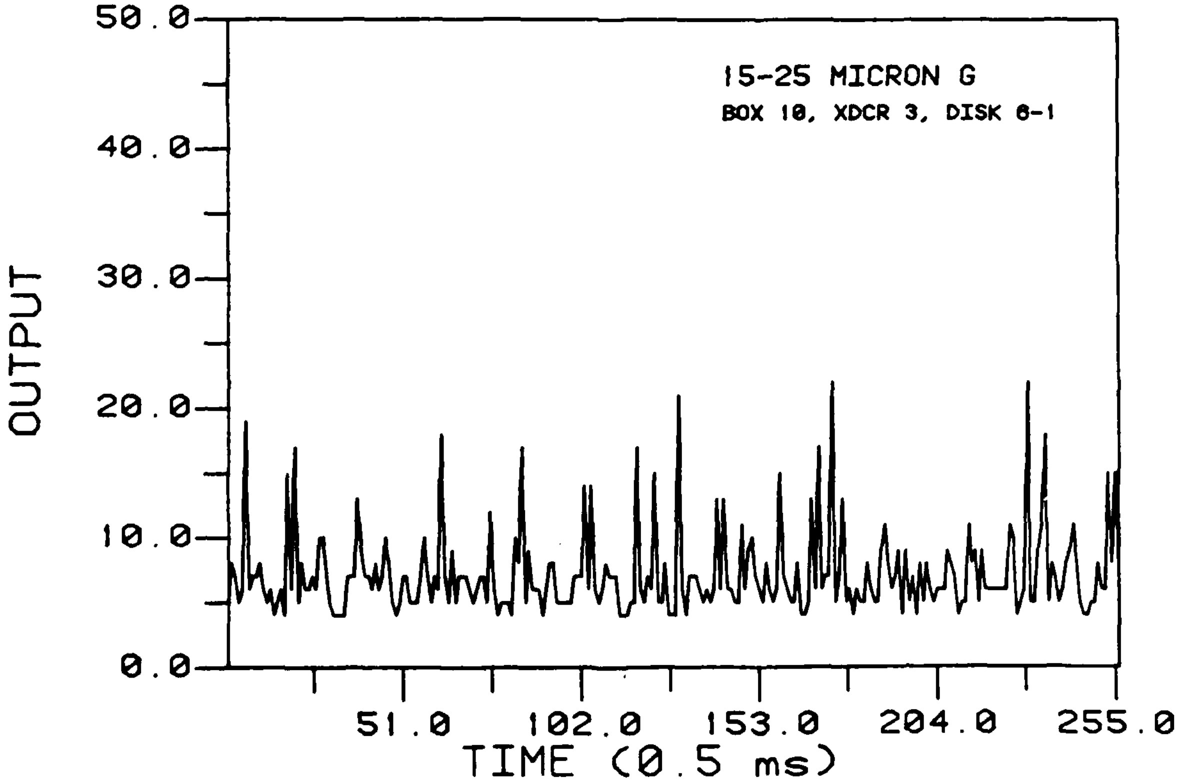

10-15 MICRON G
BOX 9, XDCR 2, DISK 3- 9
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

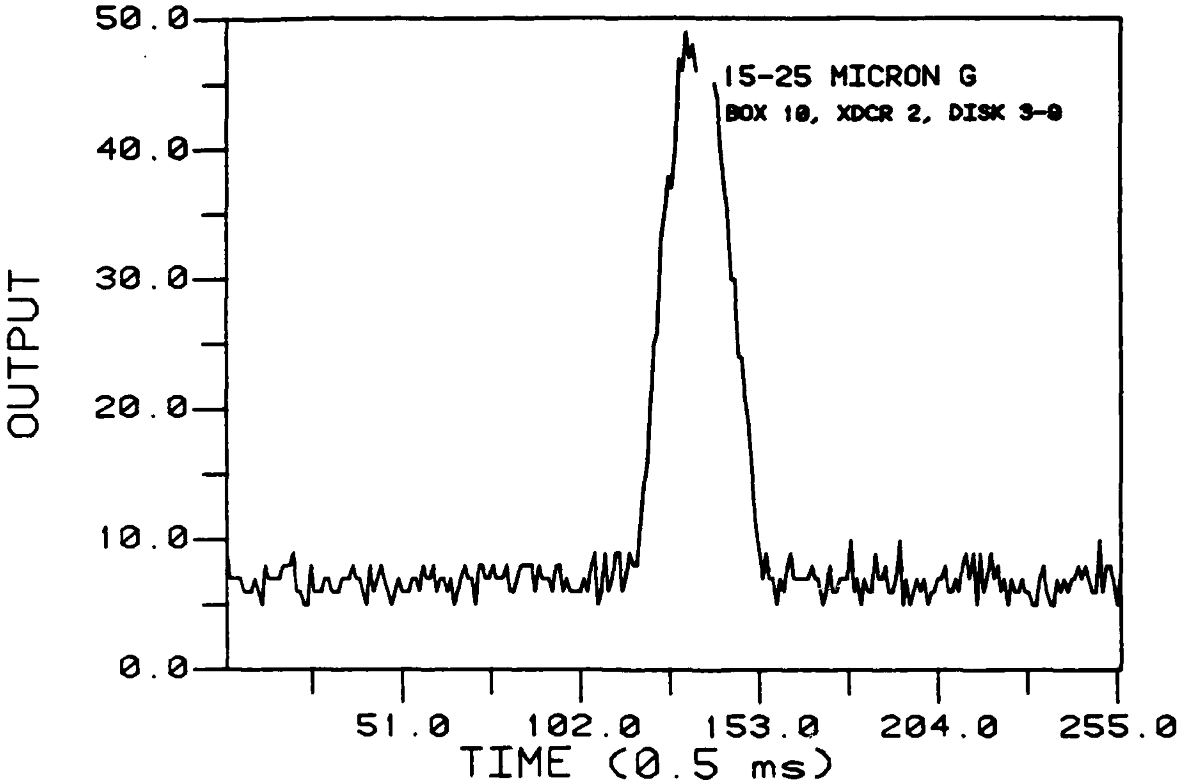

10-15 MICRON G
BOX 9, XDCR 3, DISK 3- 9
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

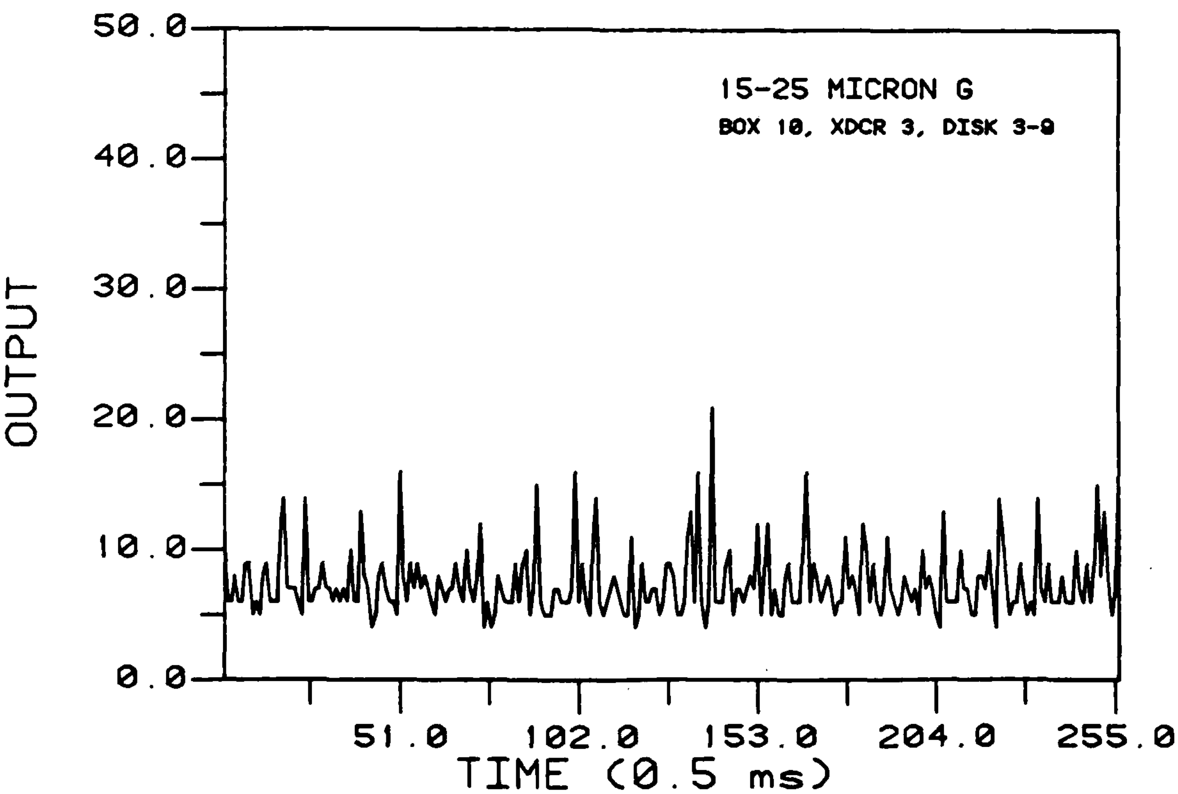

15-25 MICRON G
BOX 10, XDCR 2, DISK 6-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

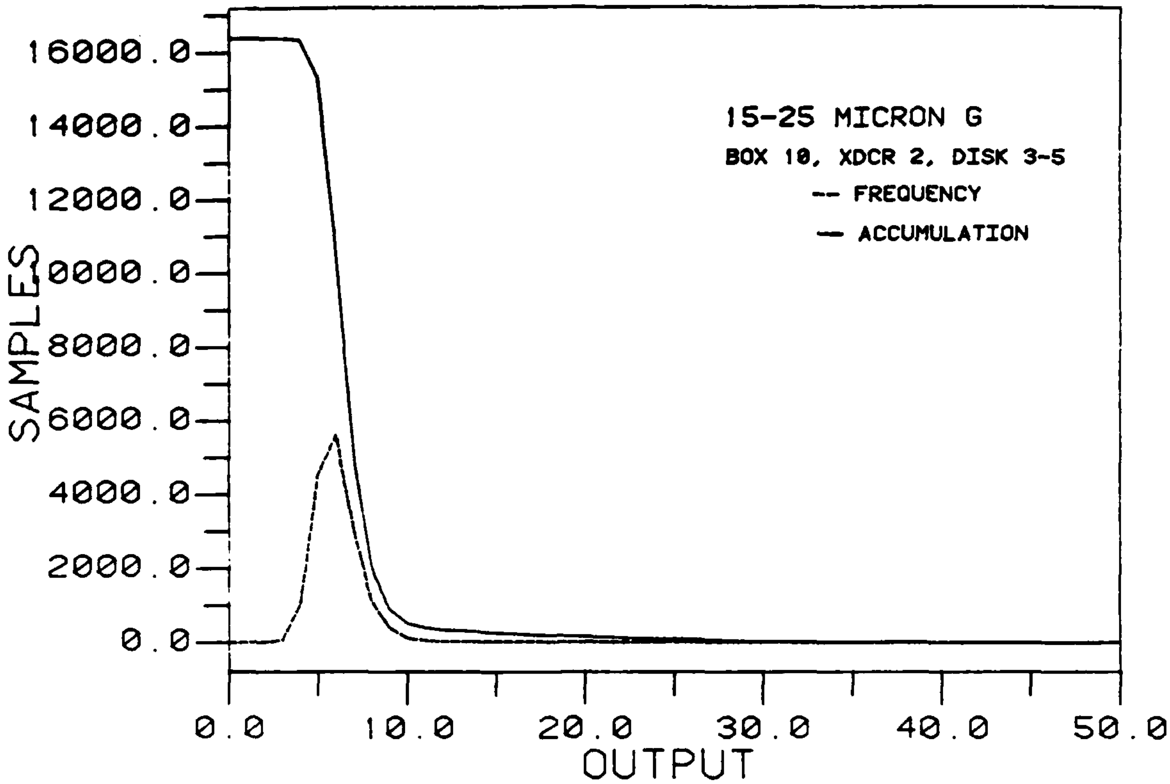

15-25 MICRON G
BOX 10, XDCR 3, DISK 6-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

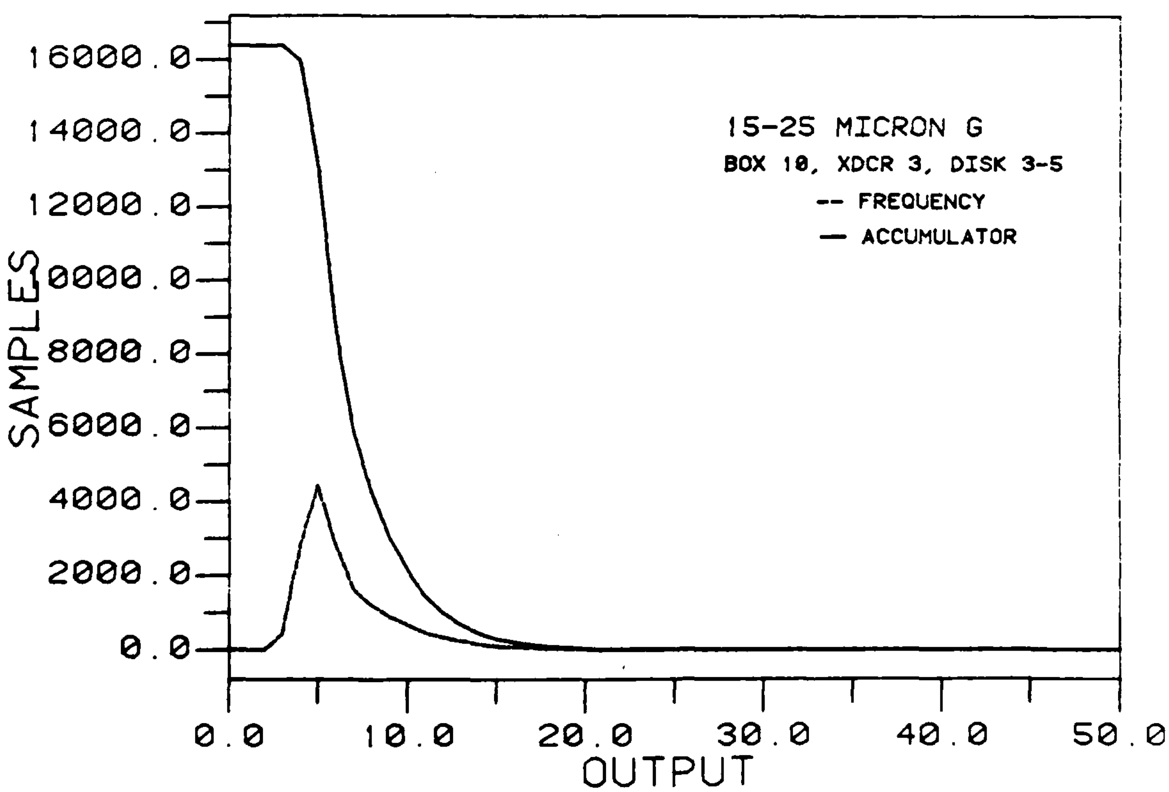

15-25 MICRON G
BOX 10, XDCR 2, DISK 6-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

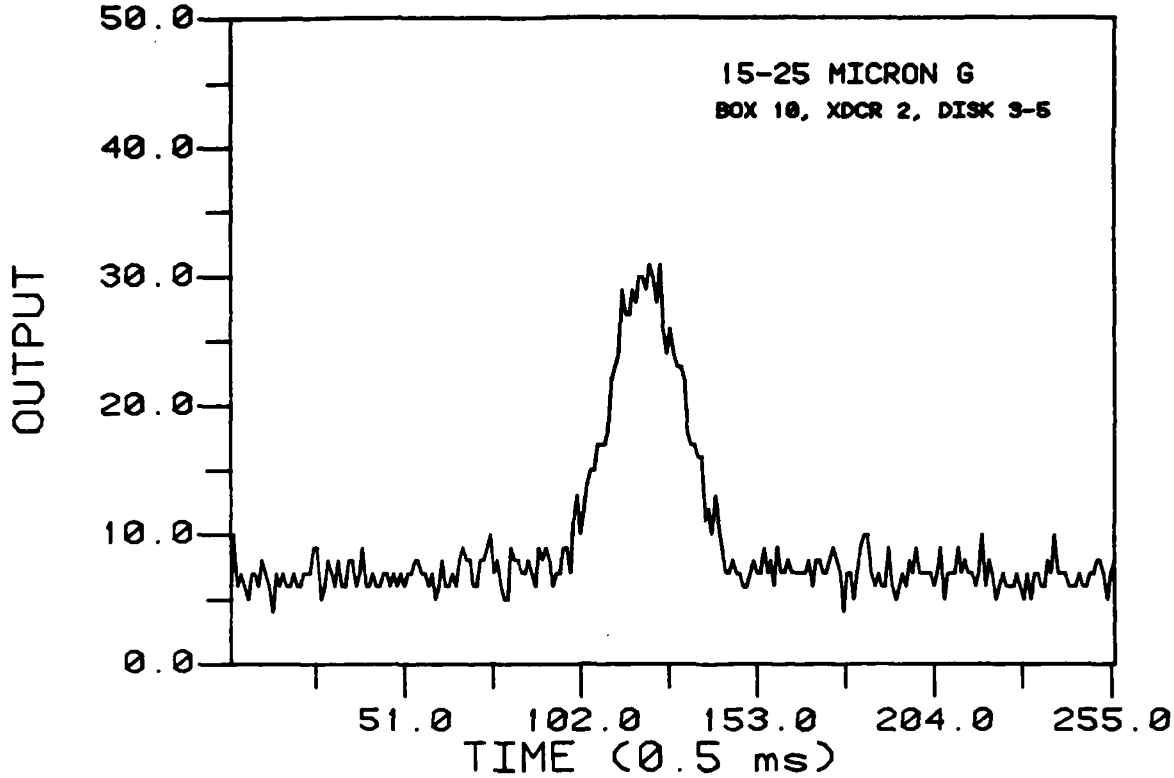

15-25 MICRON G
BOX 10, XDCR 3, DISK 6-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

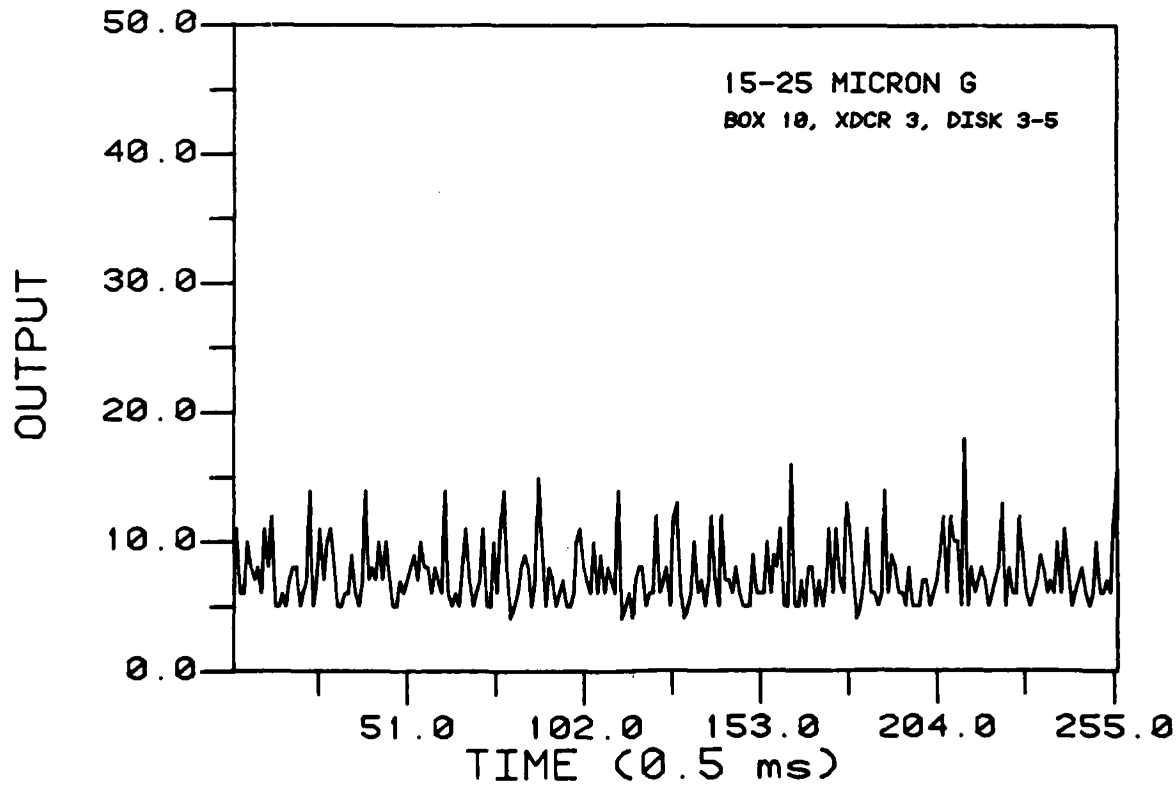

15-25 MICRON G
BOX 10, XDCR 2, DISK 3-9
OUTPUT
0.0
10.0
20.0
30.0
40.0
50.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

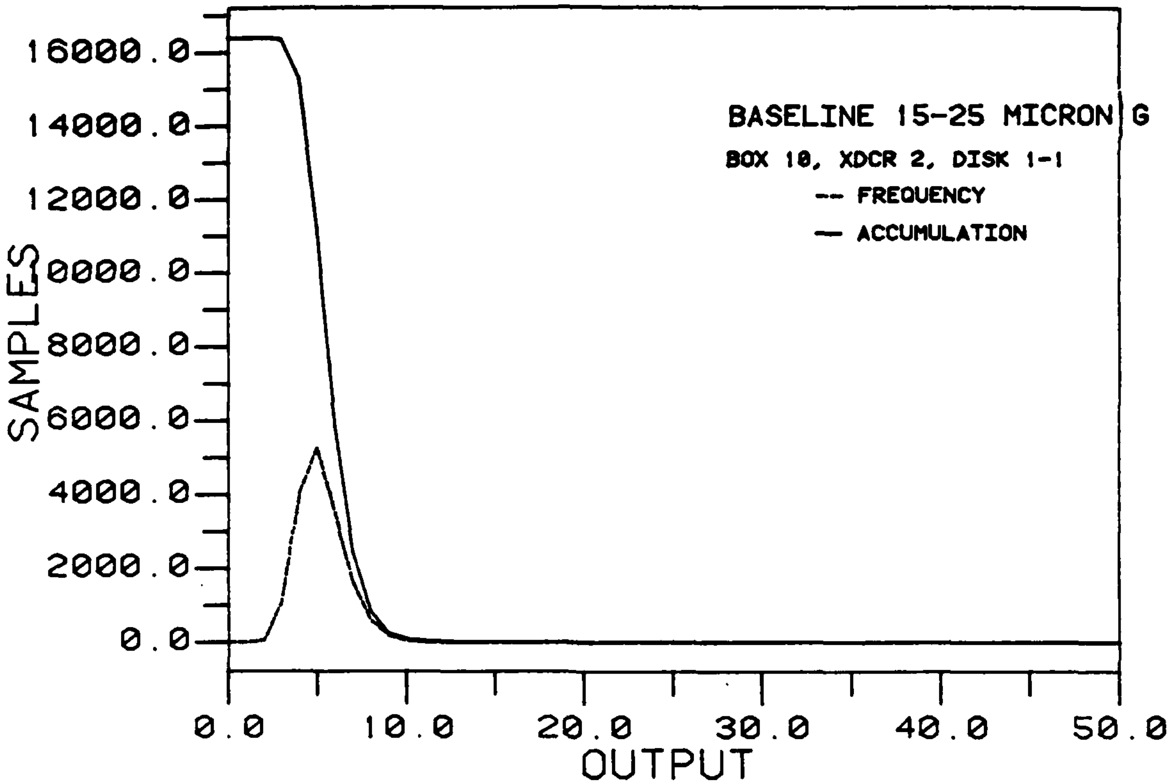

15-25 MICRON G
BOX 10, XDCR 3, DISK 3-9
OUTPUT
0.0
10.0
20.0
30.0
40.0
50.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
15-25 MICRON G
BOX 10, XDCR 2, DISK 3-5
-- FREQUENCY
— ACCUMULATION

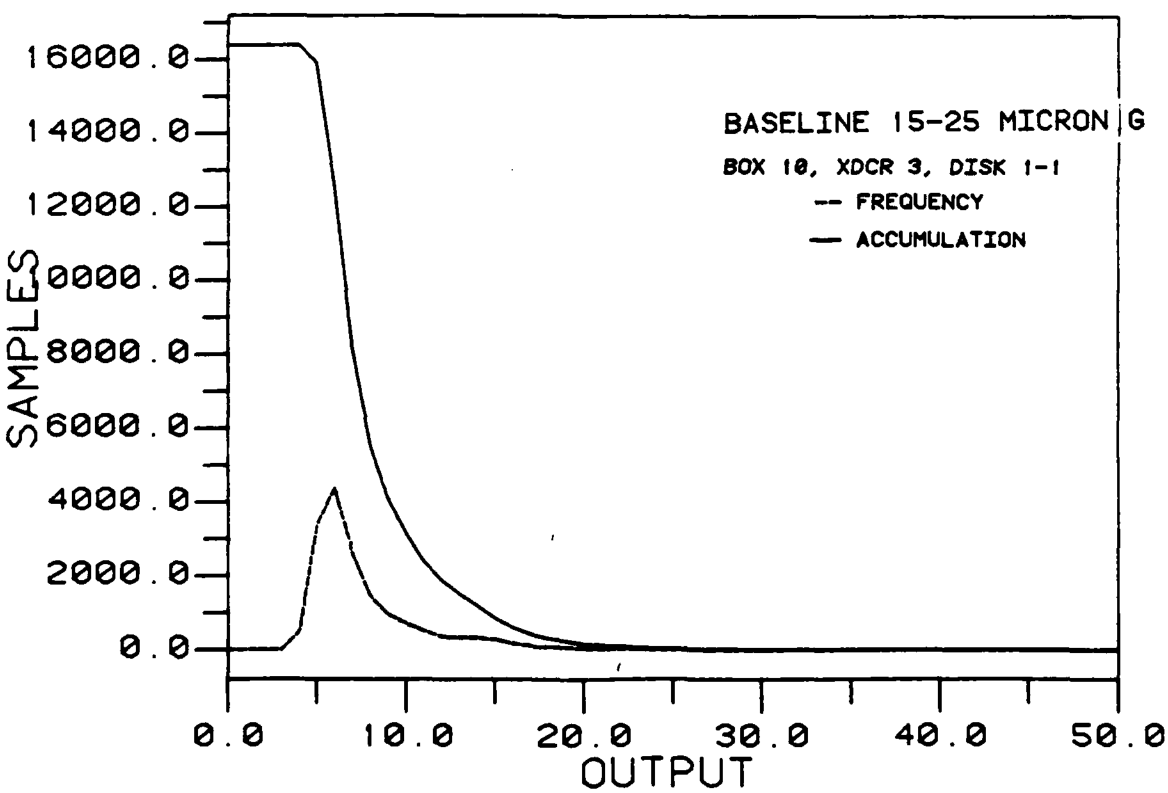

16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
15-25 MICRON G
BOX 10, XDCR 3, DISK 3-5
-- FREQUENCY
— ACCUMULATOR


50.0
40.0
30.0
20.0
10.0
0.0
OUTPUT
15-25 MICRON G
BOX 10, XDCR 2, DISK 3-5
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

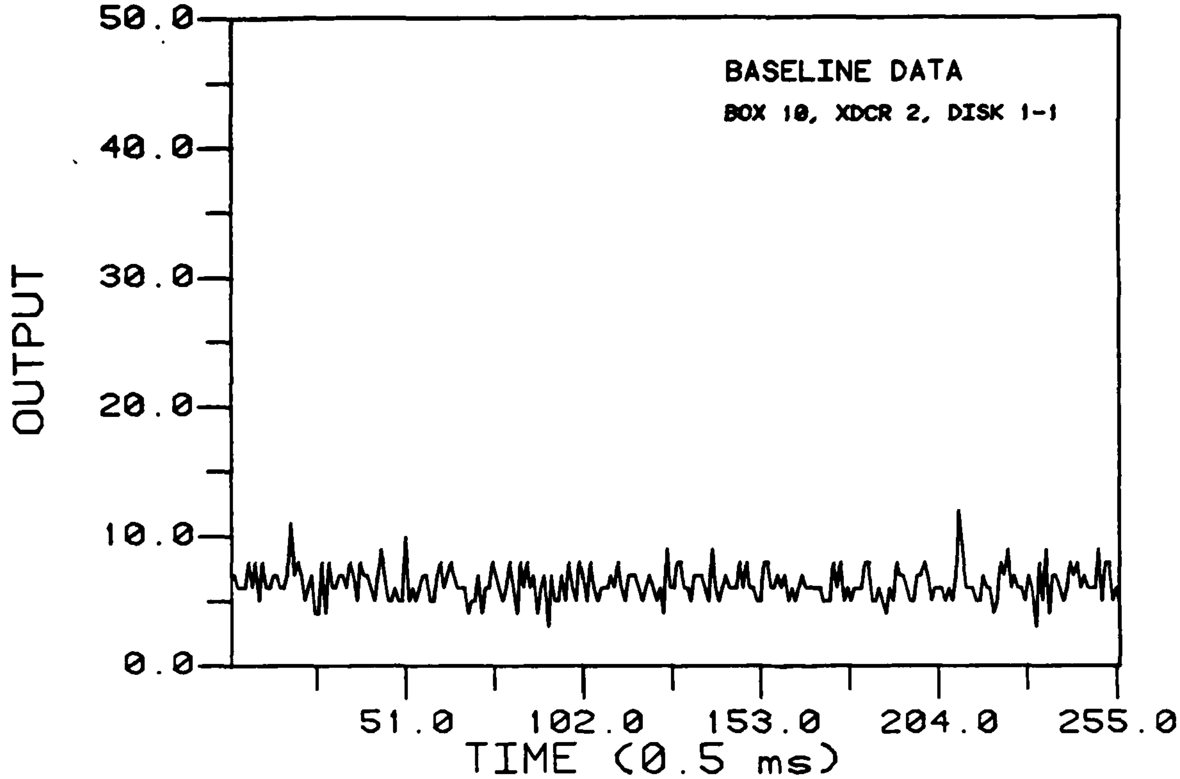

50.0
40.0
30.0
20.0
10.0
0.0
OUTPUT
15-25 MICRON G
BOX 10, XDCR 3, DISK 3-5
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

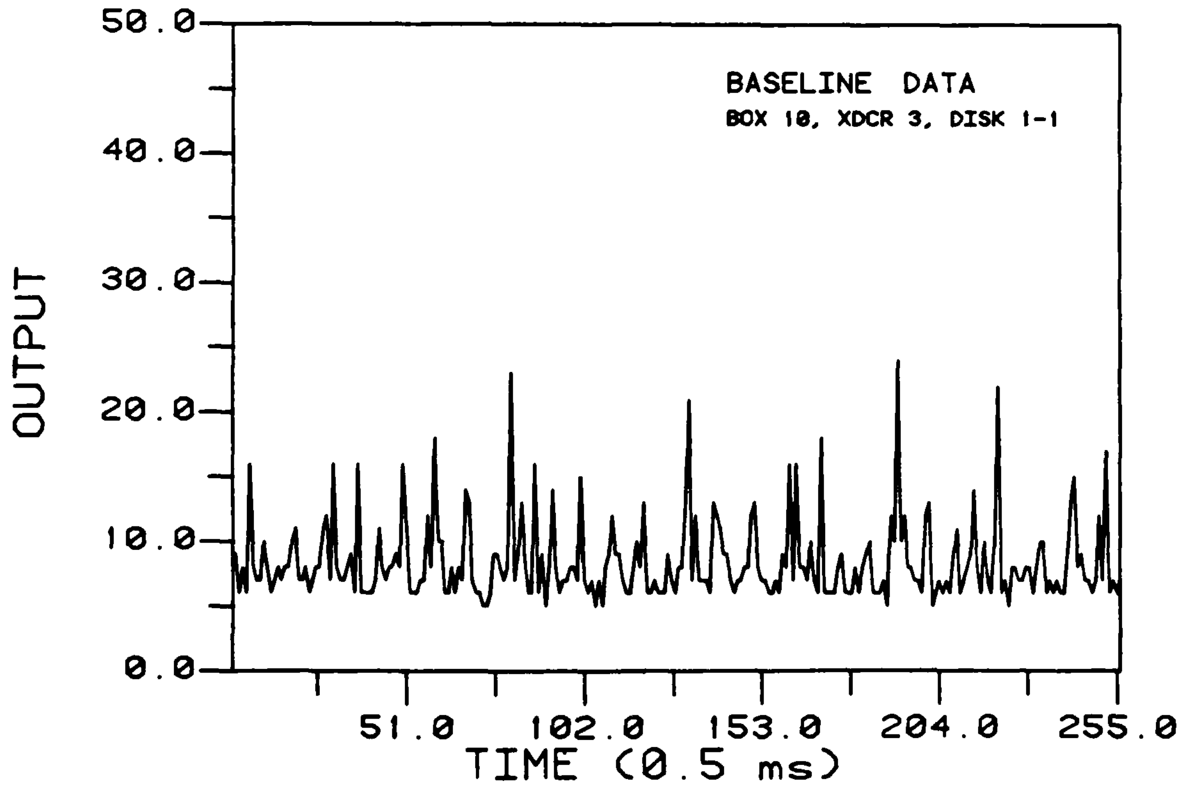


BASELINE 15-25 MICRON G
BOX 10, XDCR 2, DISK 1-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT



BASELINE 15-25 MICRON G
BOX 10, XDCR 3, DISK 1-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT


BASELINE DATA
BOX 10, XDCR 2, DISK 1-1
OUTPUT
TIME (0.5 ms)
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0


BASELINE DATA
BOX 10, XDCR 3, DISK 1-1
OUTPUT
TIME (0.5 ms)
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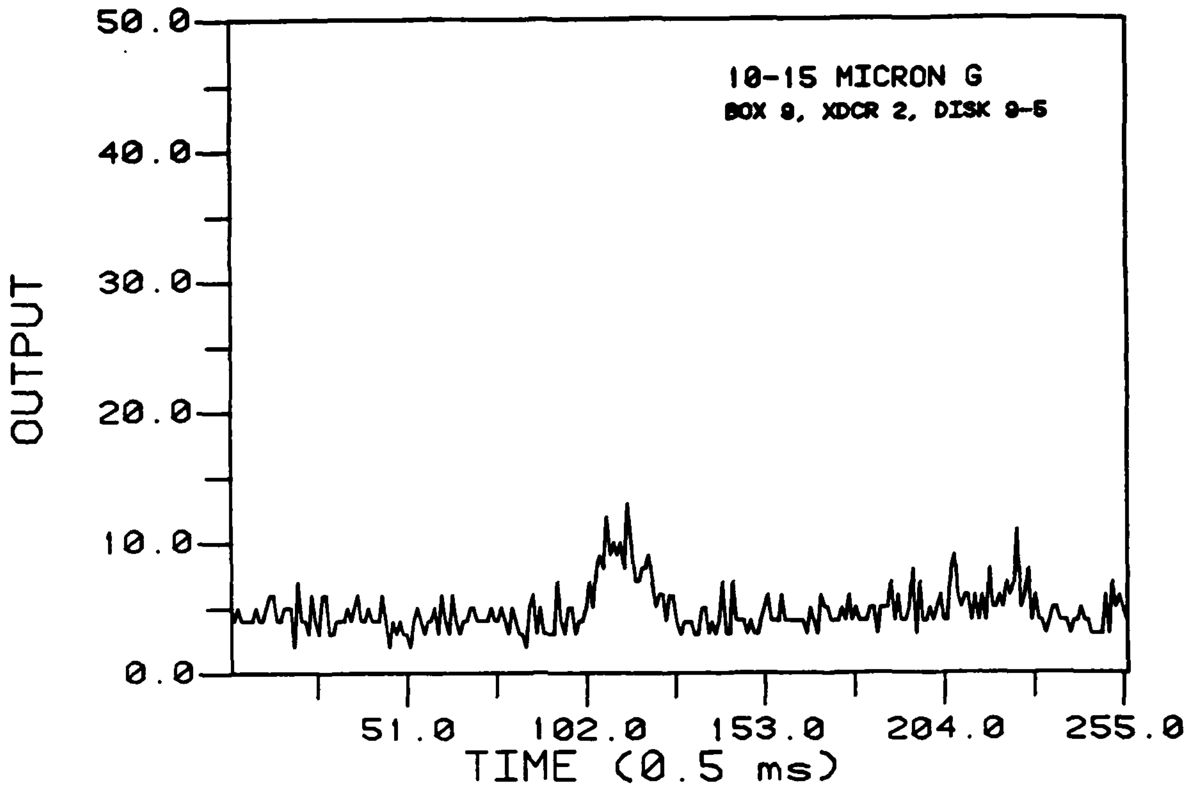
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0


10-15 MICRON G
BOX 9, XDCR 2, DISK 9-5
OUTPUT
50.0
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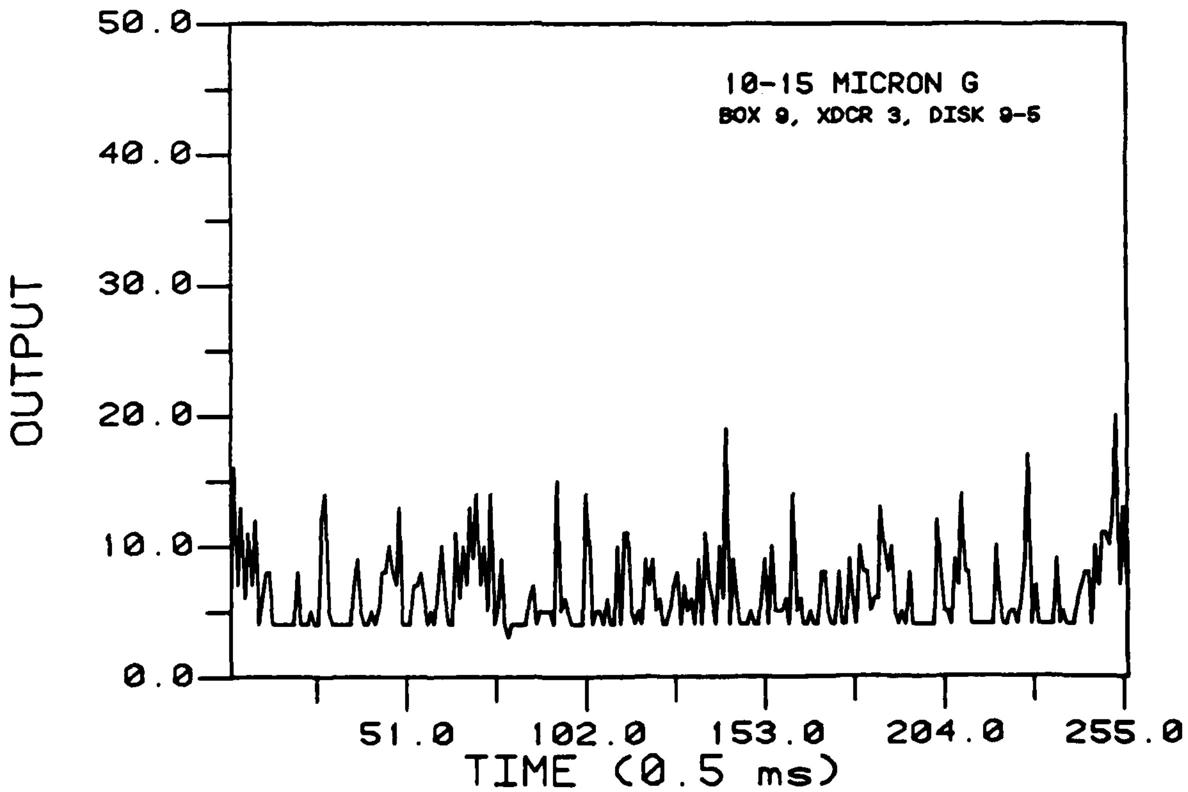
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


10-15 MICRON G
BOX 9, XDCR 3, DISK 9-5
OUTPUT
50.0
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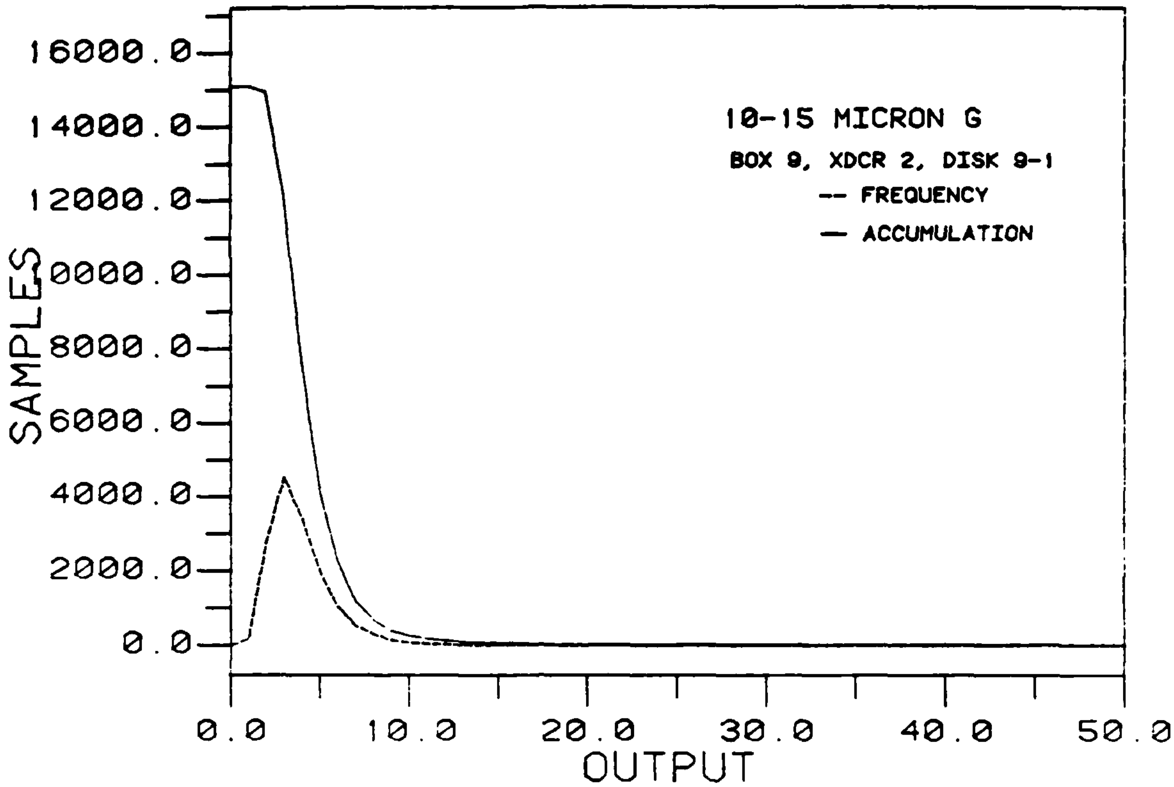
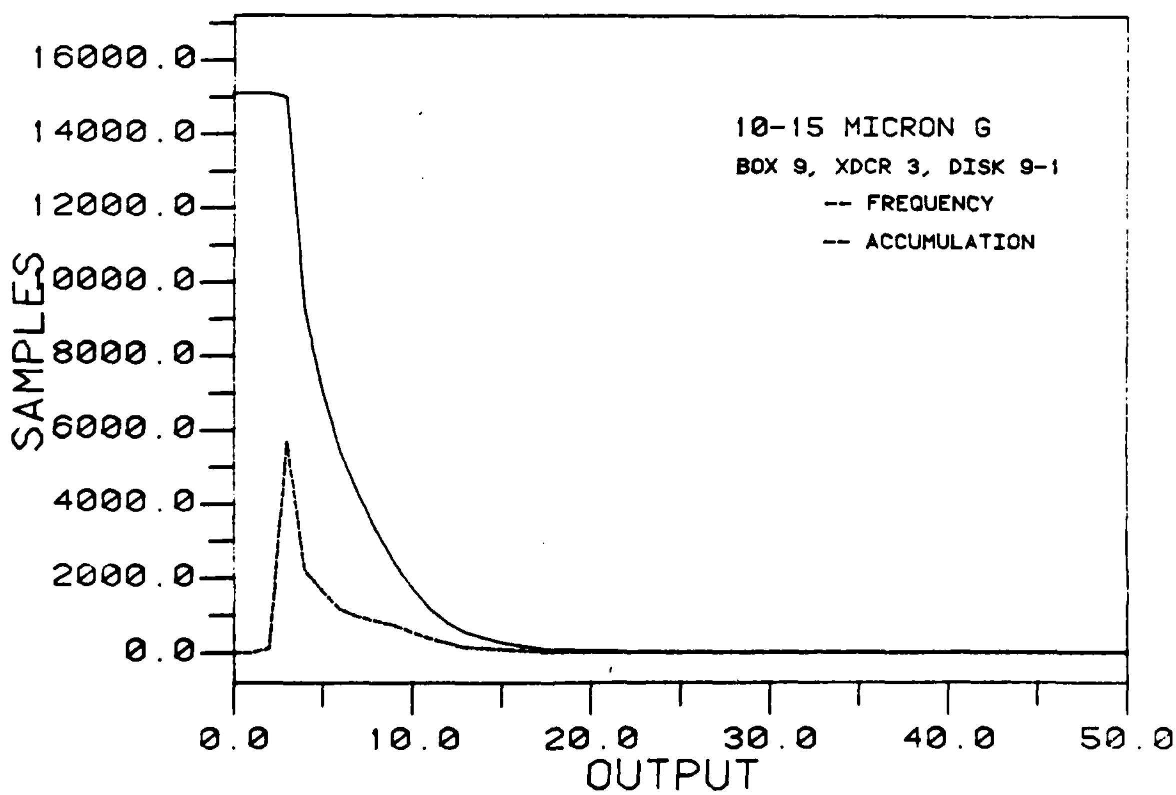
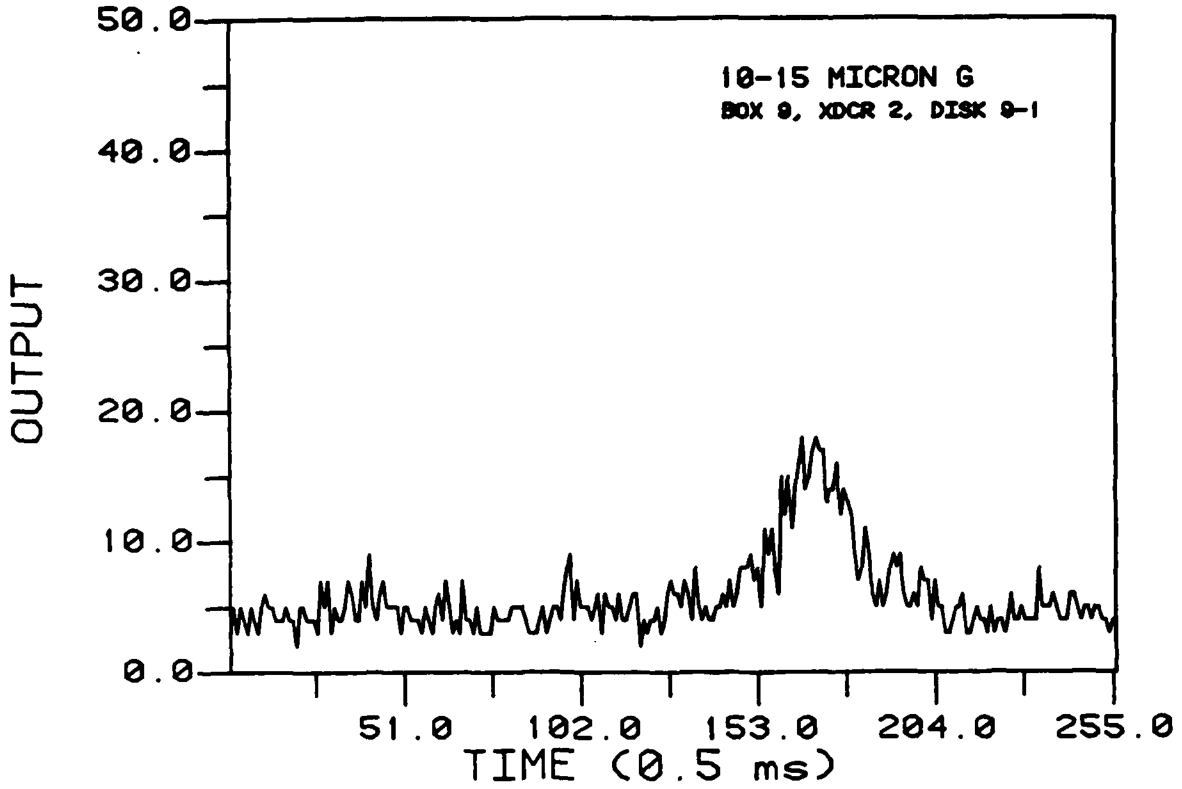
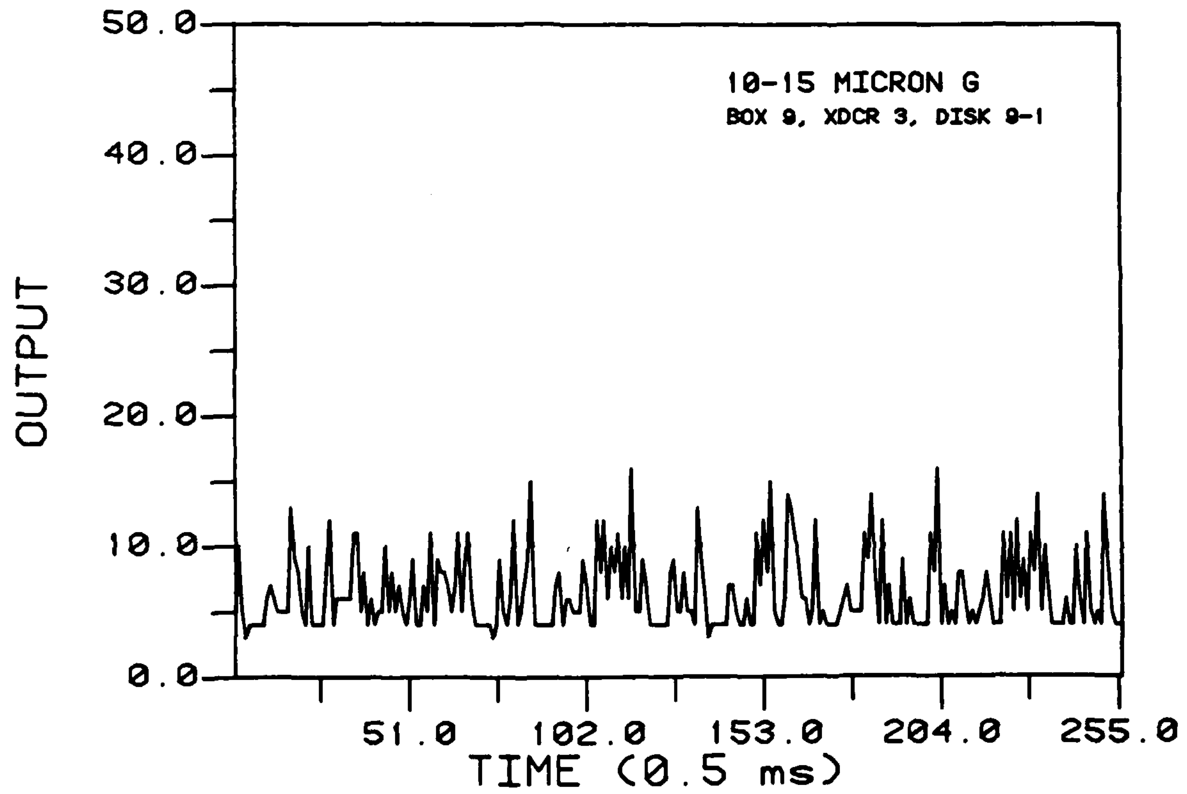
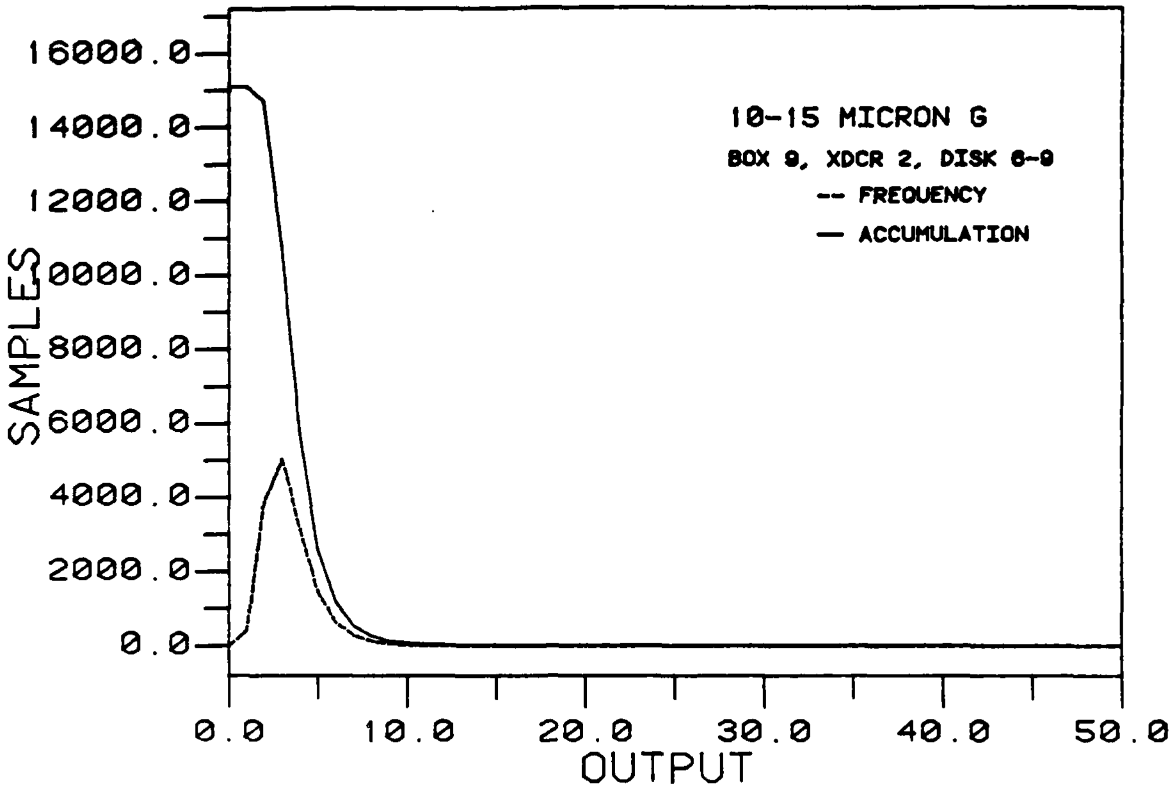
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

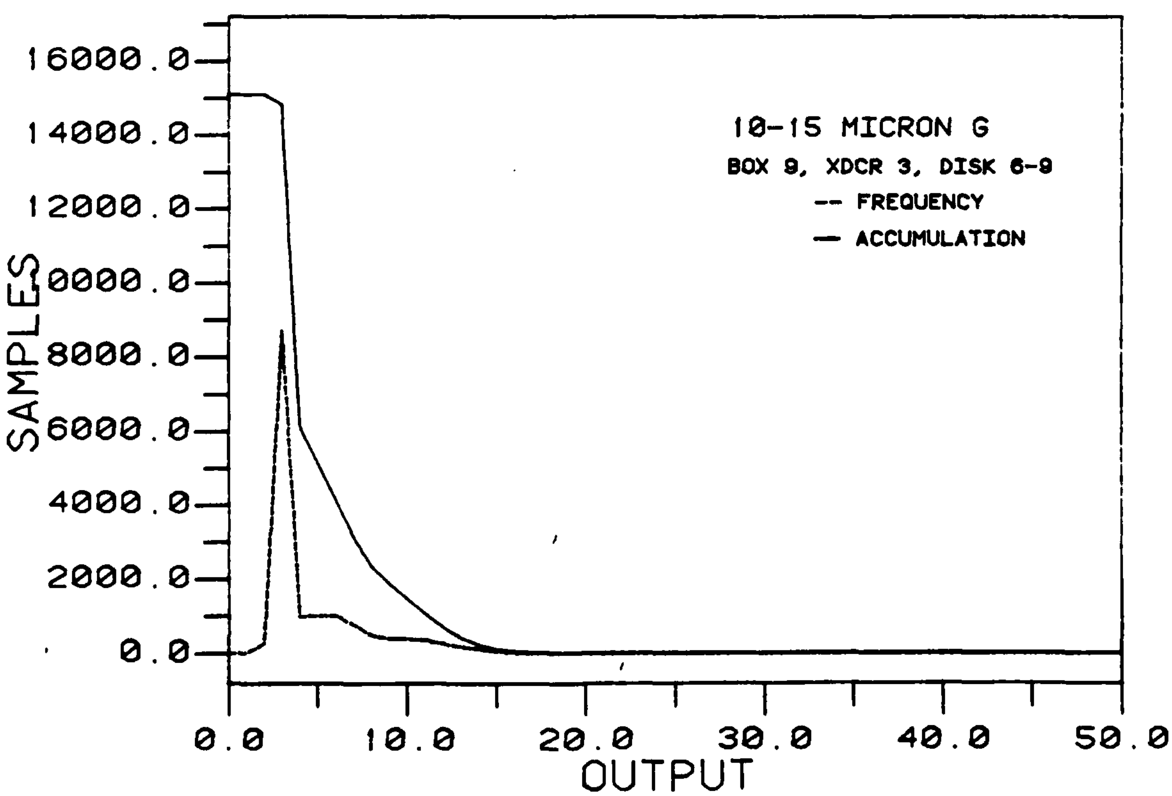

16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
10-15 MICRON G
BOX 9, XDCR 2, DISK 9-1
-- FREQUENCY
— ACCUMULATION
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT


16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
10-15 MICRON G
BOX 9, XDCR 3, DISK 9-1
-- FREQUENCY
-- ACCUMULATION
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT


10-15 MICRON G
BOX 9, XDCR 2, DISK 9-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


10-15 MICRON G
BOX 9, XDCR 3, DISK 9-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


10-15 MICRON G
BOX 9, XDCR 2, DISK 6-9
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT


10-15 MICRON G
BOX 9, XDCR 3, DISK 6-9
-- FREQUENCY
— ACCUMULATION
SAMPLES
16000.0
14000.0
12000.0
10000.0
8000.0
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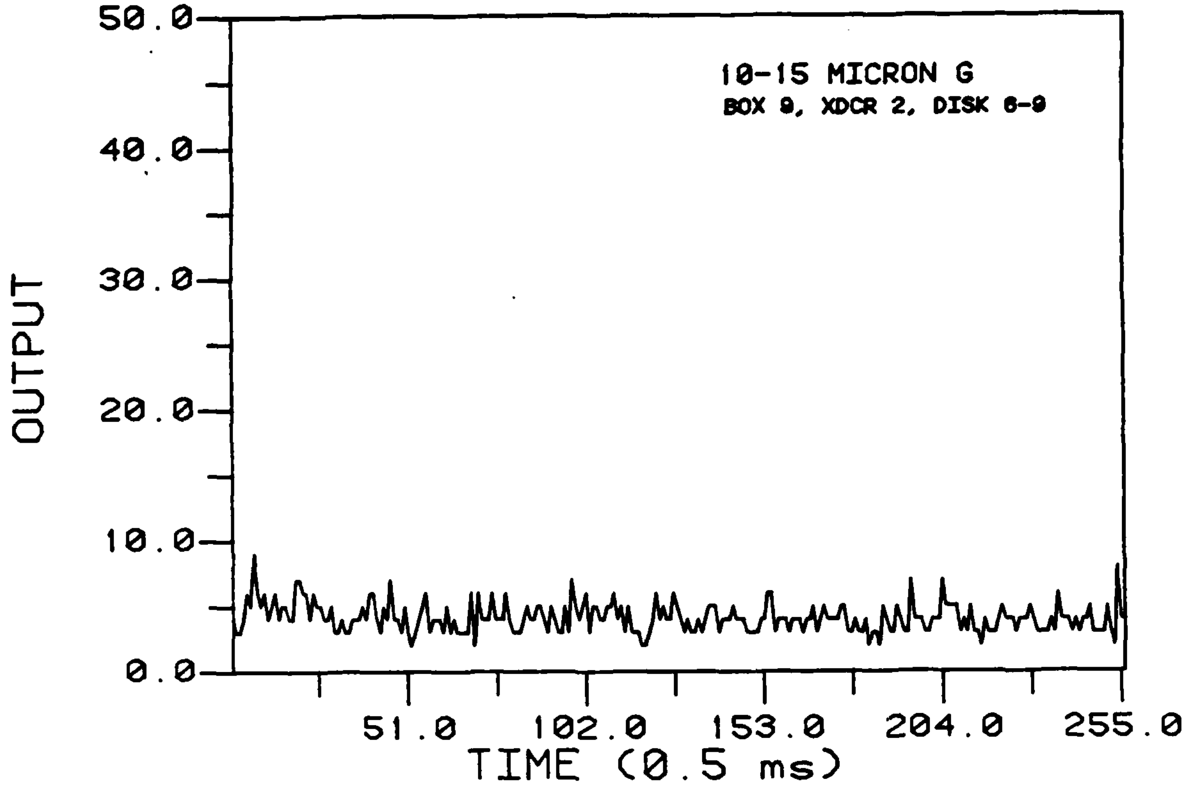
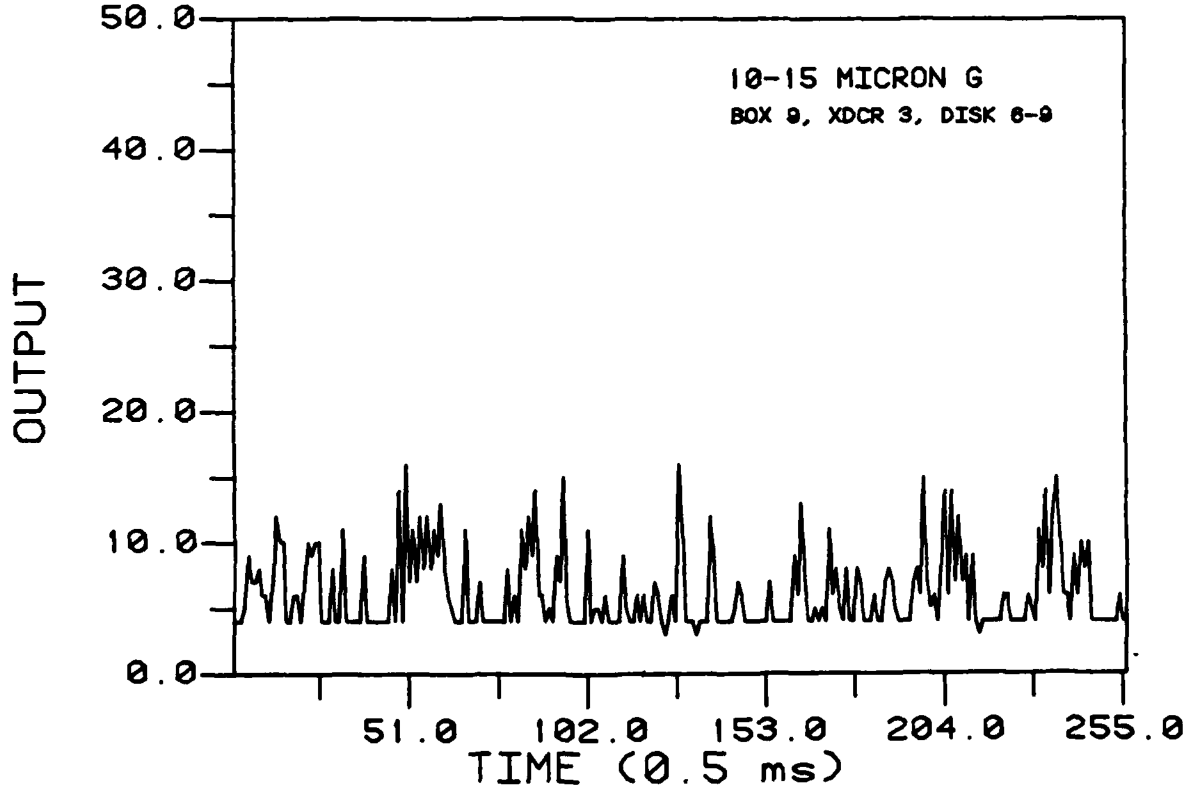
4000.0
2000.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT



10-15 MICRON G
BOX 9, XDCR 2, DISK 6-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



10-15 MICRON G
BOX 9, XDCR 3, DISK 6-9
OUTPUT
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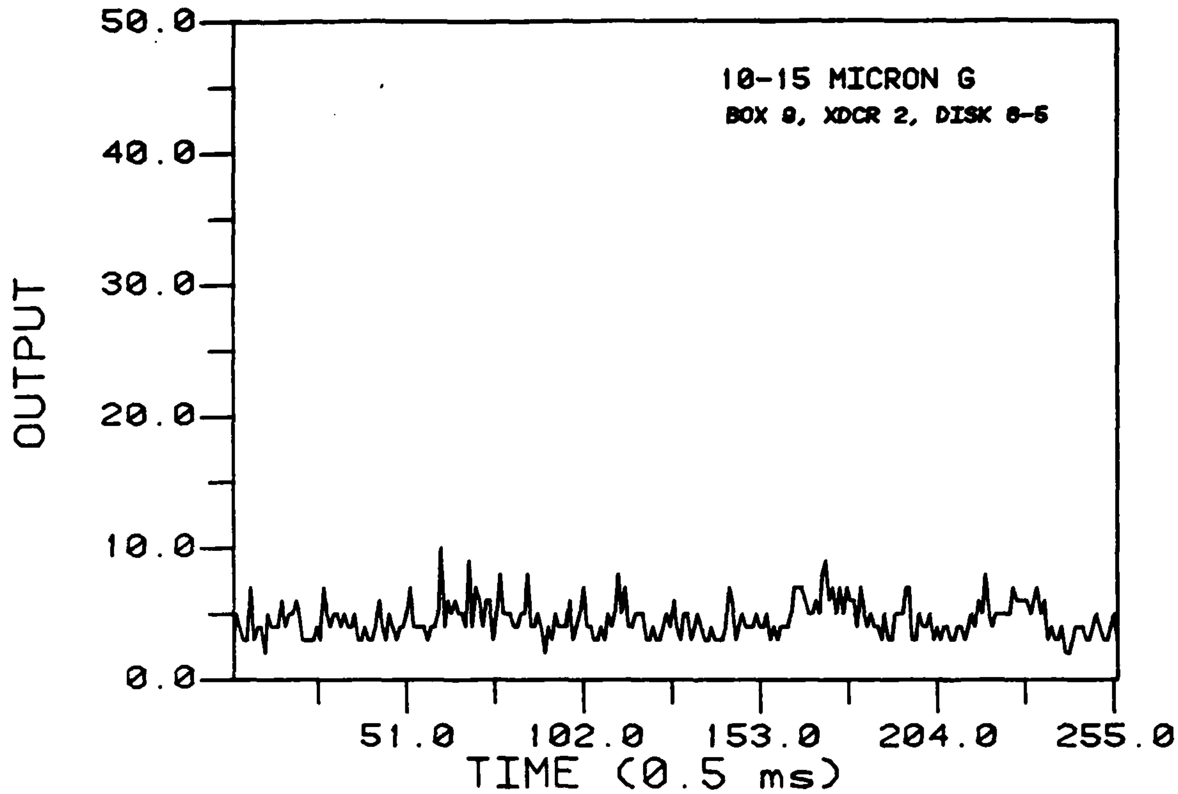
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)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BOX 9, XDCR 2, DISK 6-5
OUTPUT
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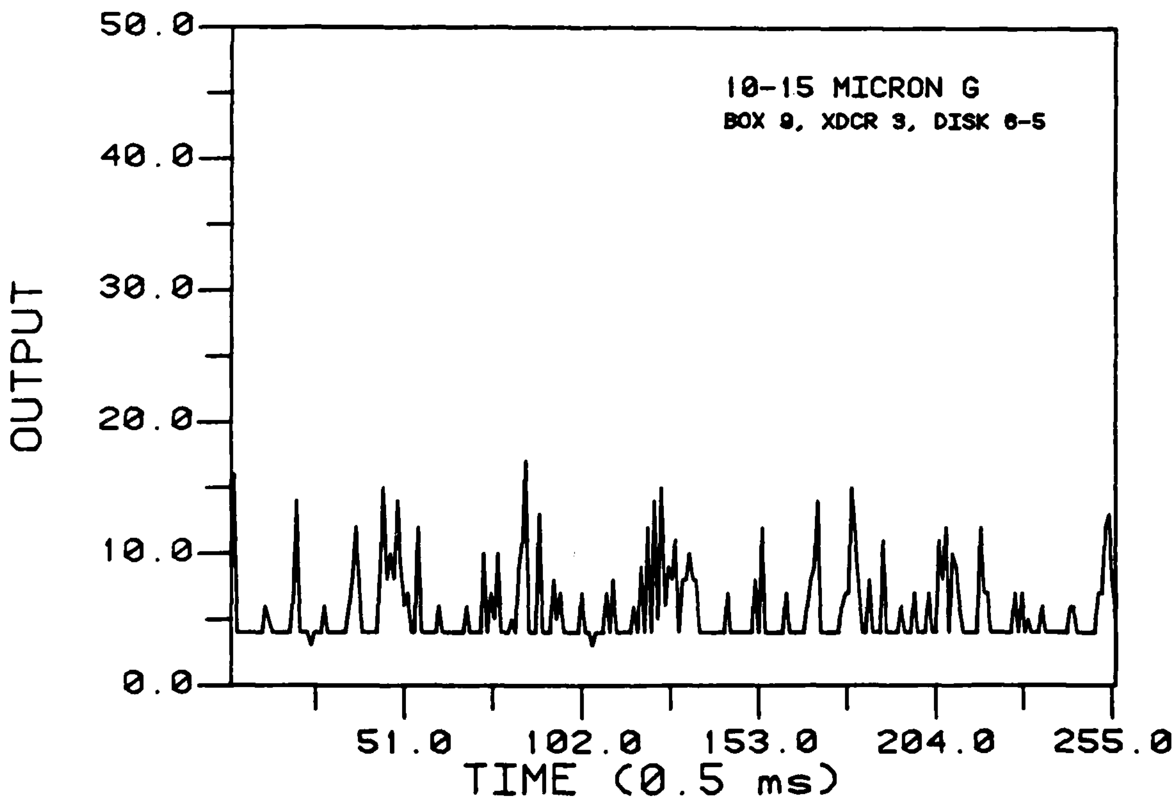
20.0
30.0
40.0
50.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


10-15 MICRON G
BOX 9, XDCR 3, DISK 6-5
OUTPUT
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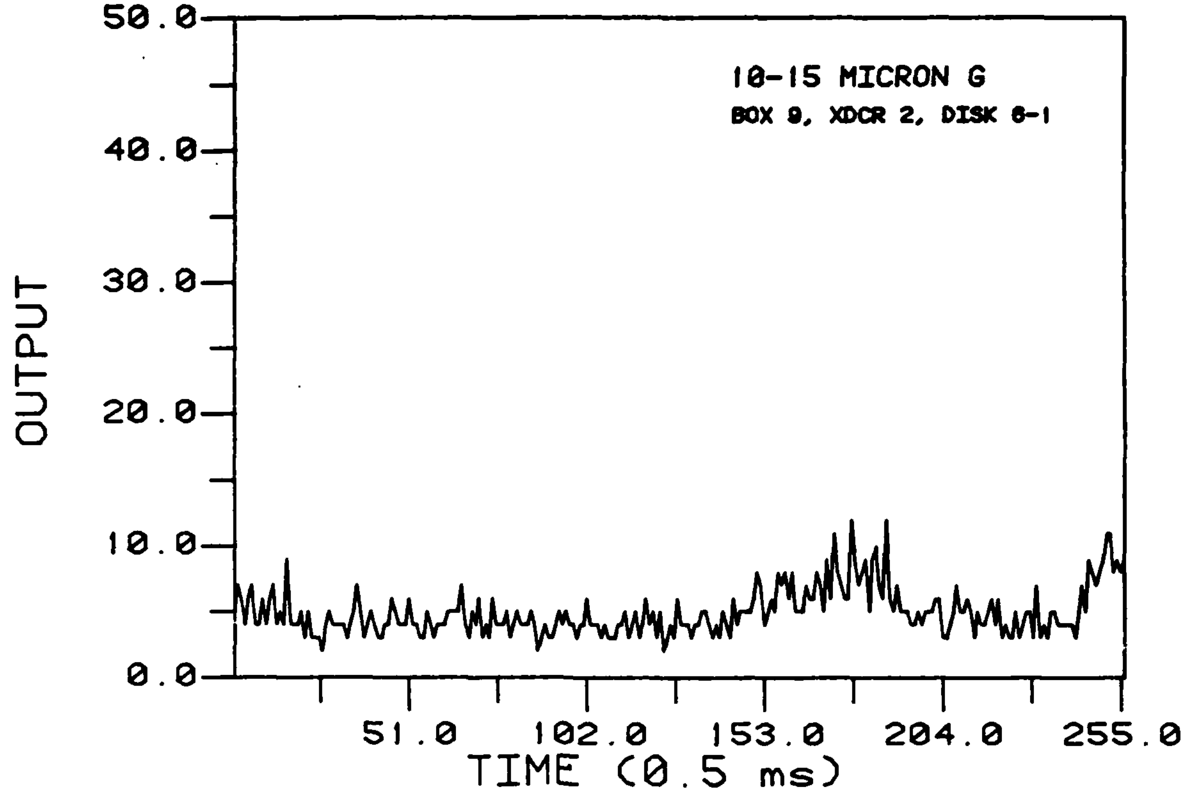
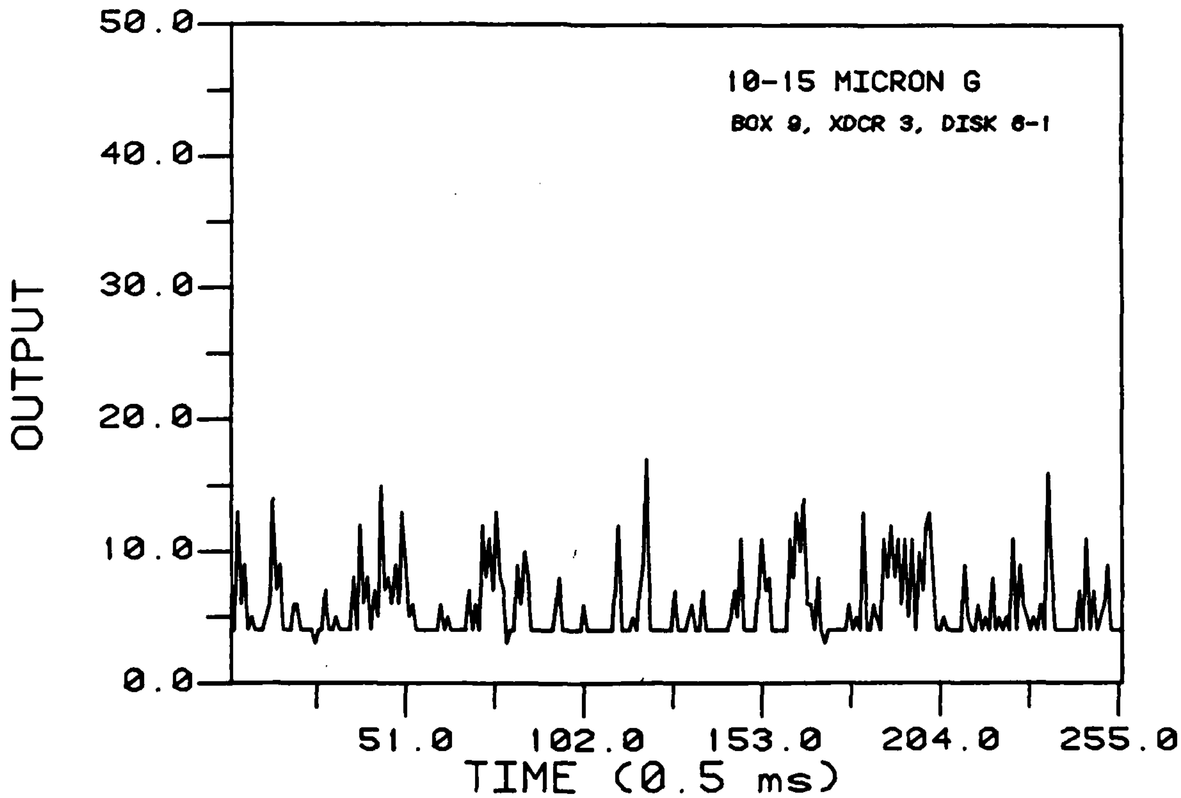
10.0
20.0
30.0
40.0
50.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


10-15 MICRON G
BOX 9, XDCR 2, DISK 6-1
OUTPUT
TIME (0.5 ms)
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0


10-15 MICRON G
BOX 9, XDCR 3, DISK 6-1
OUTPUT
TIME (0.5 ms)
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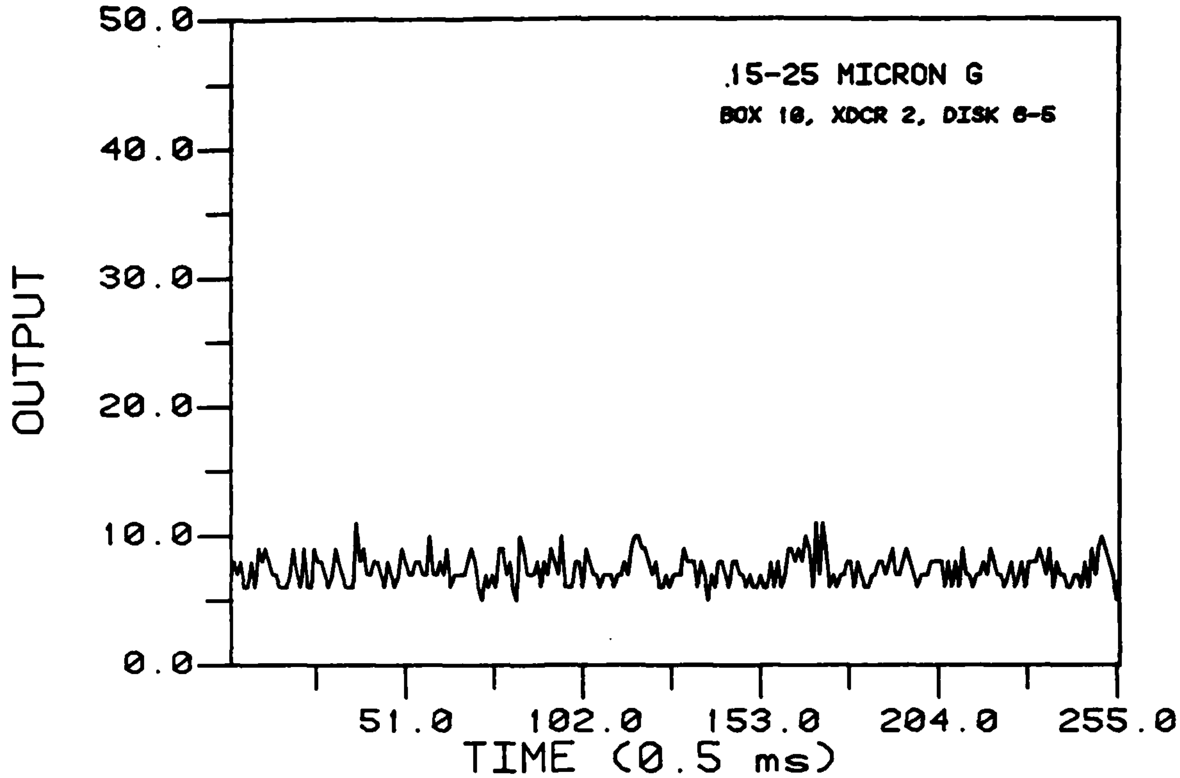
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0


15-25 MICRON G
BOX 10, XDCR 2, DISK 6-5
OUTPUT
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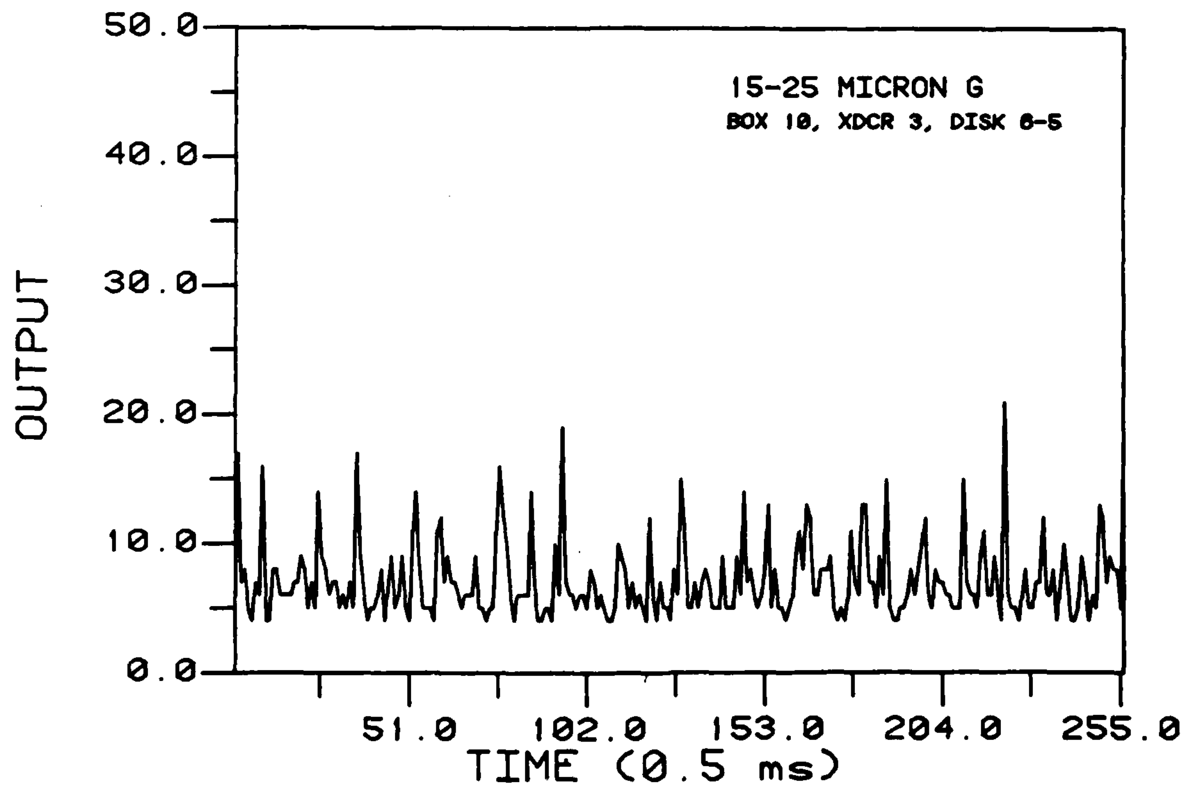
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


15-25 MICRON G
BOX 10, XDCR 3, DISK 6-5
OUTPUT
50.0
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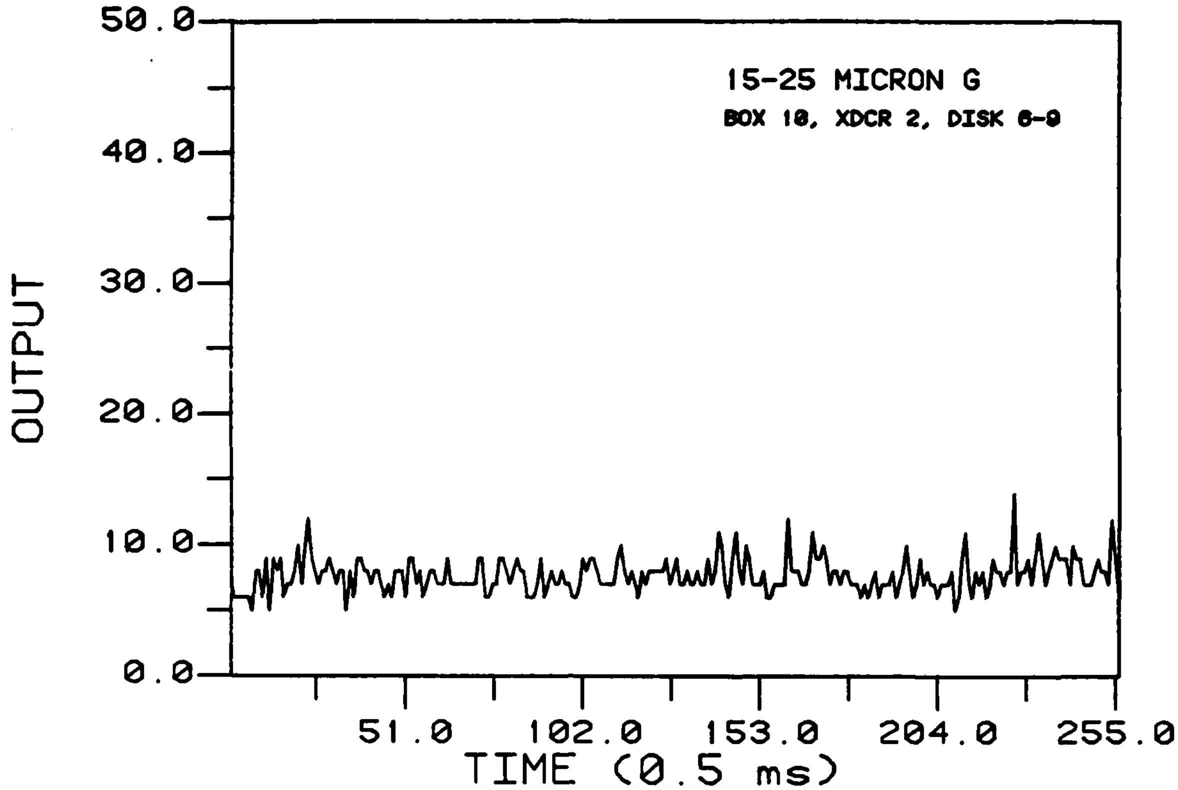
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


15-25 MICRON G
BOX 10, XDCR 2, DISK 6-9
OUTPUT
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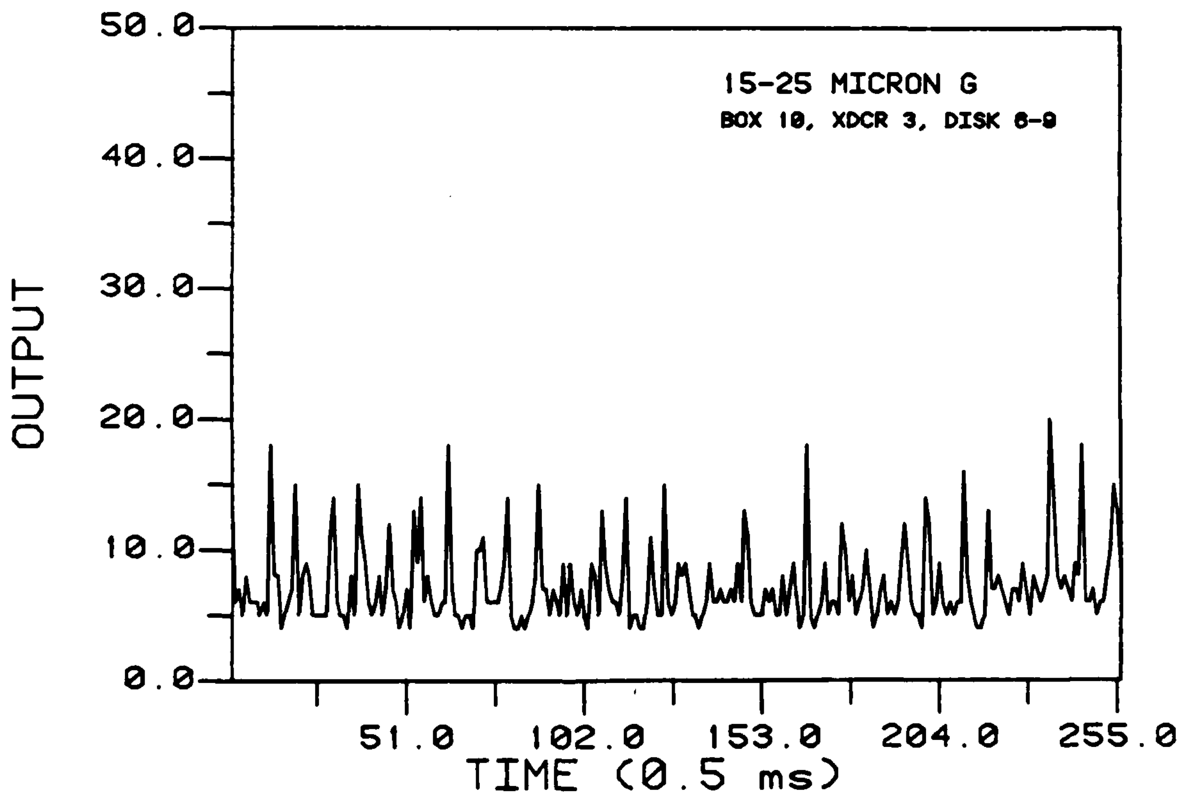
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


15-25 MICRON G
BOX 10, XDCR 3, DISK 6-9
OUTPUT
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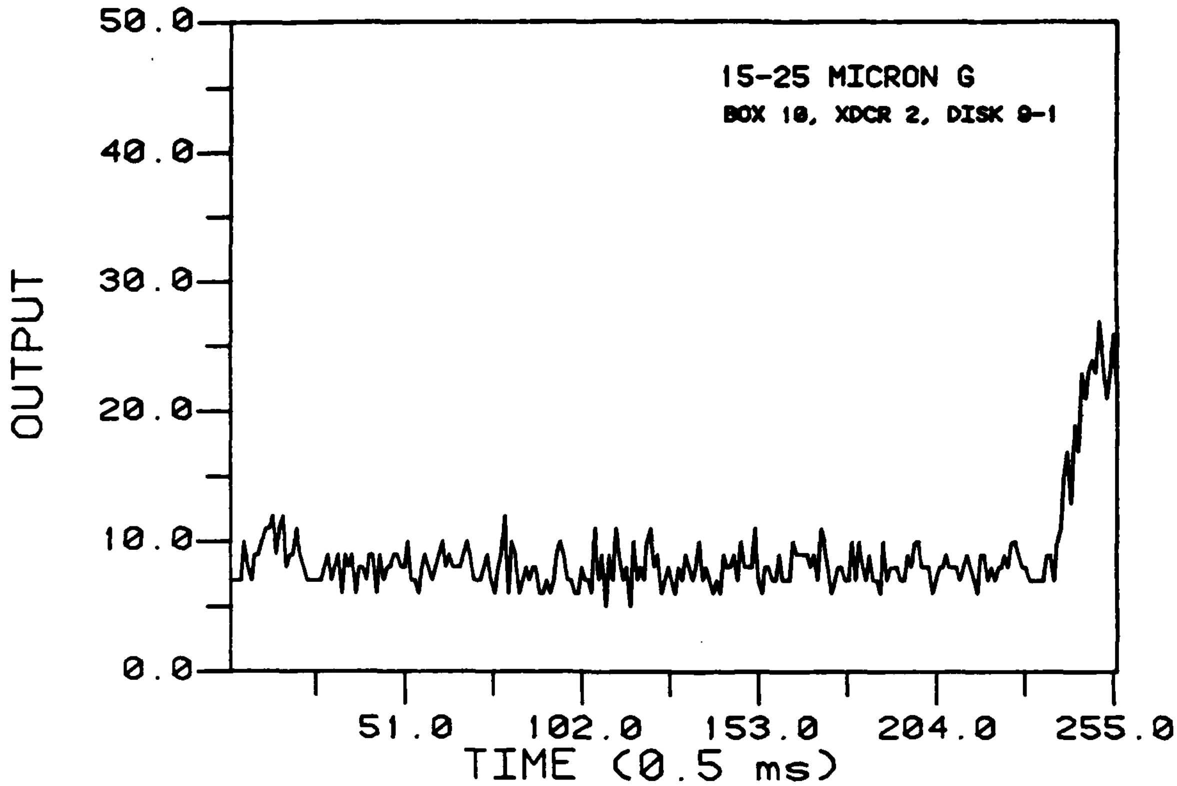
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



15-25 MICRON G
BOX 10, XDCR 2, DISK 9-1
OUTPUT
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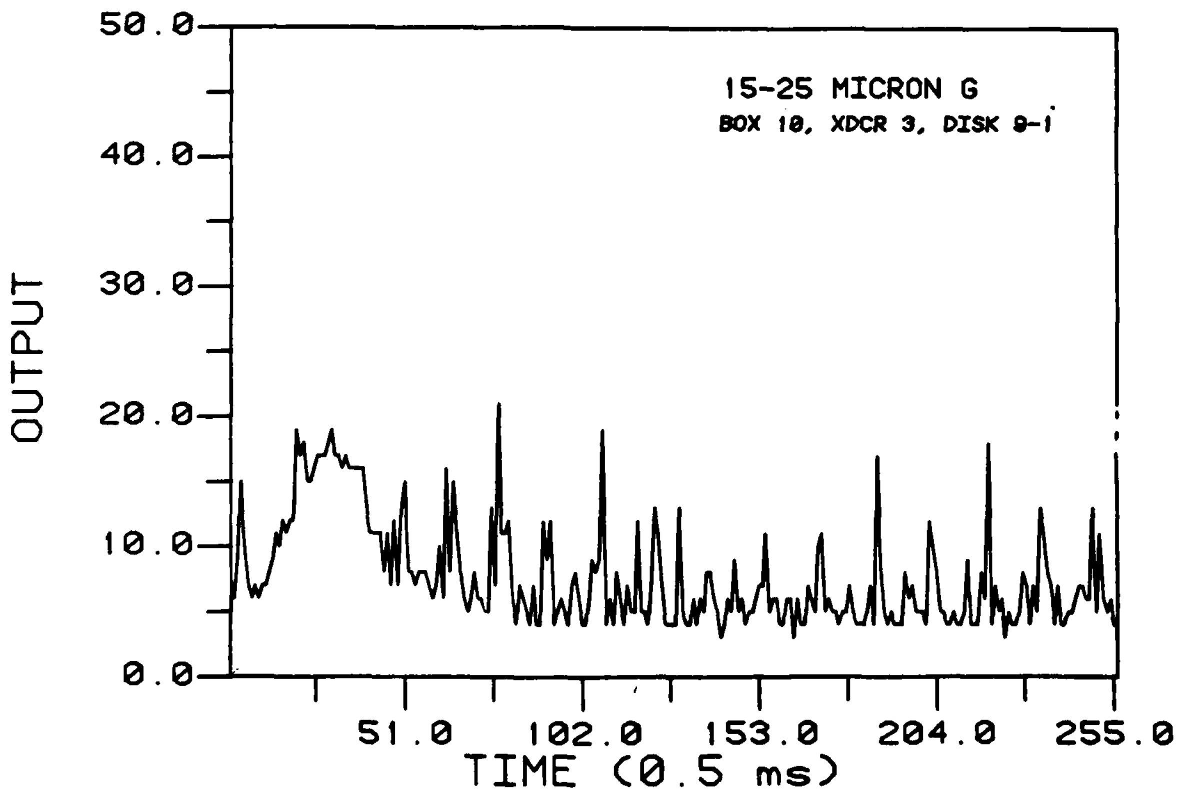
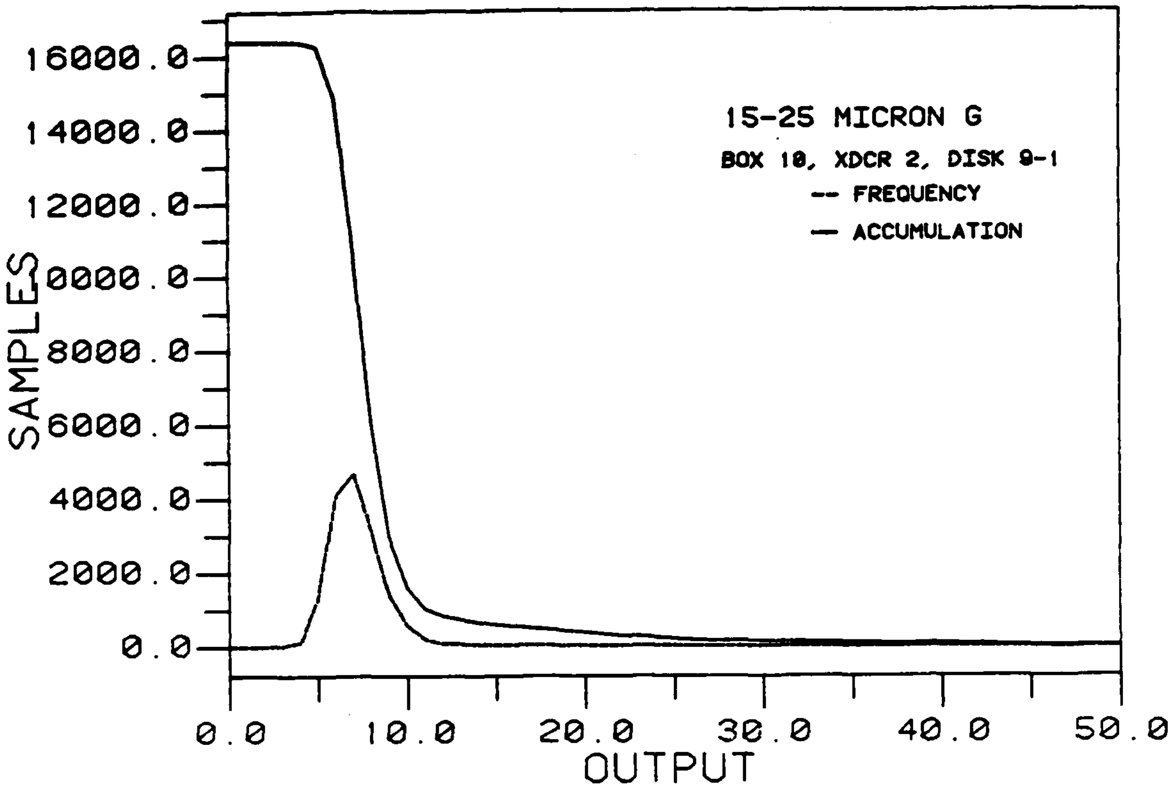
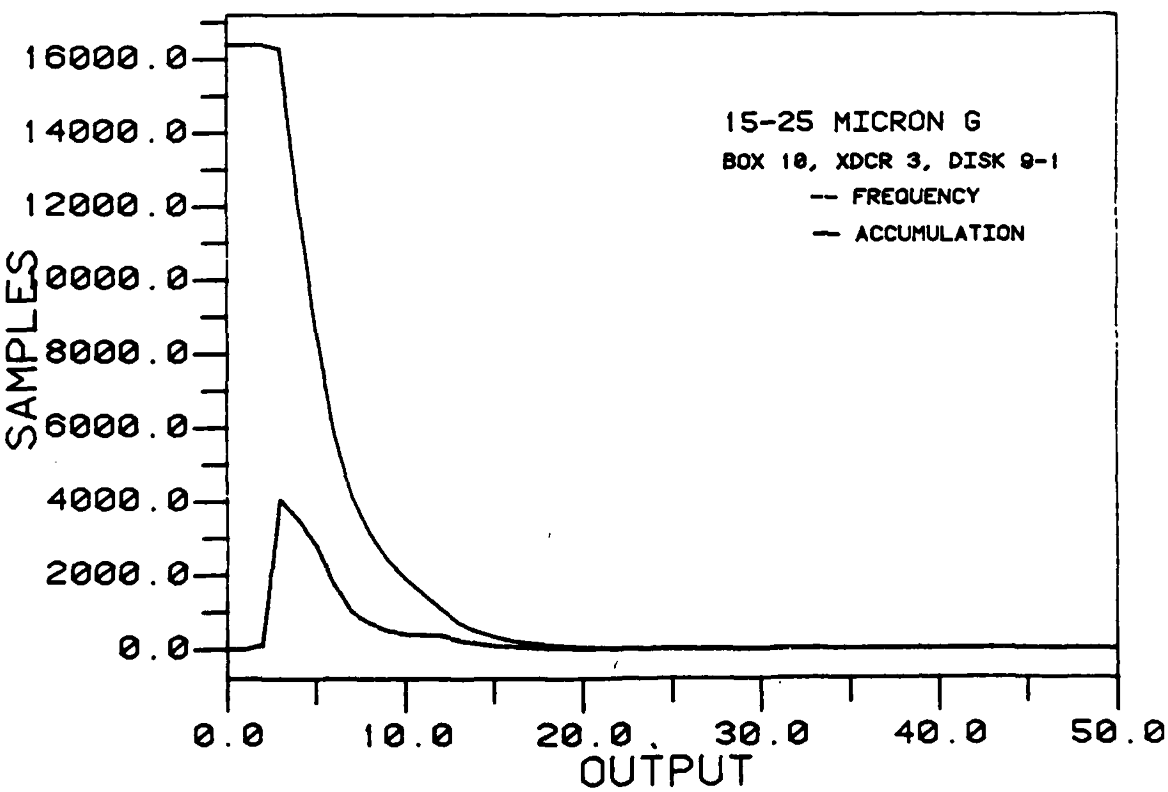
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



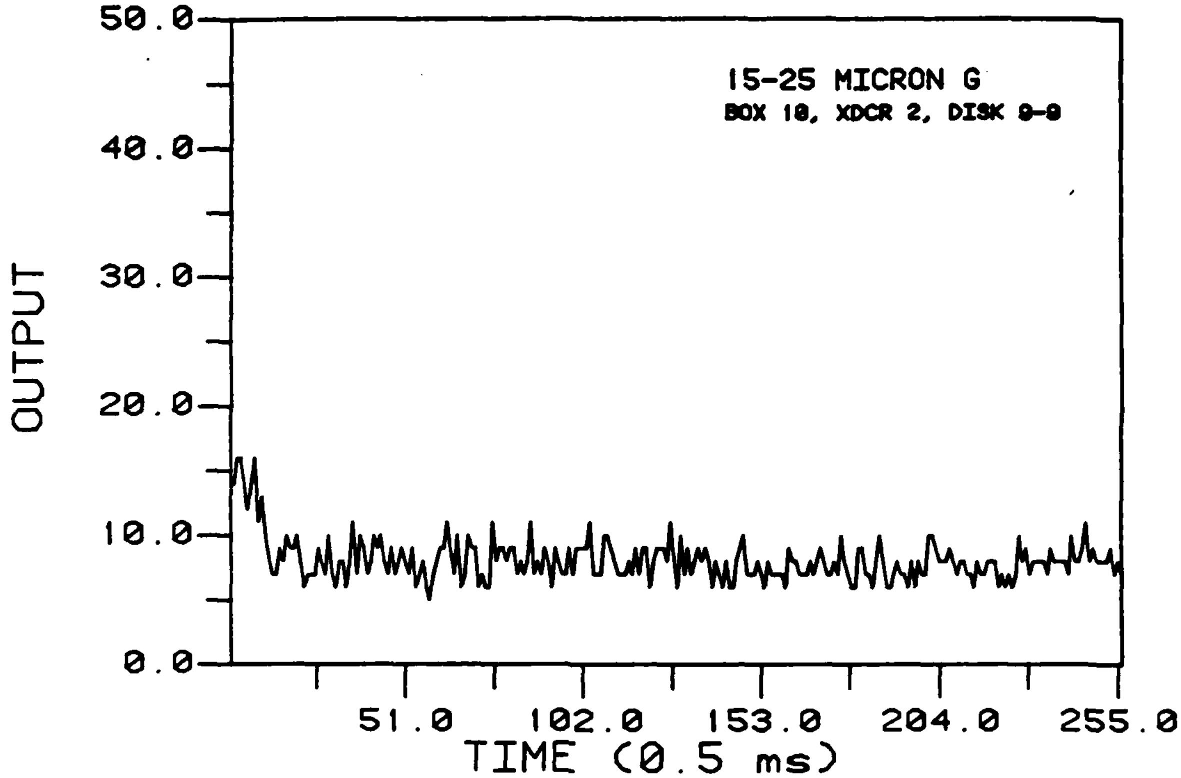
15-25 MICRON G
BOX 10, XDCR 3, DISK 9-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



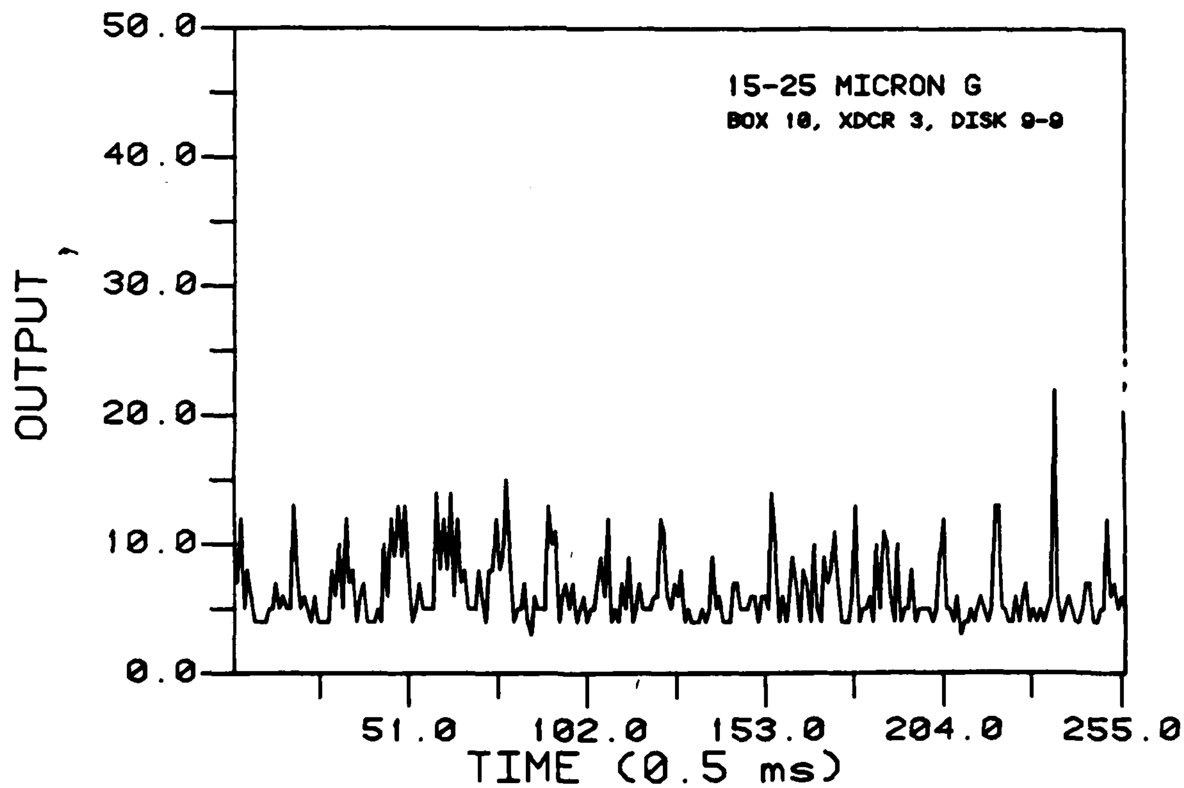
15-25 MICRON G
BOX 10, XDCR 2, DISK 9-1
-- FREQUENCY
— ACCUMULATION
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT



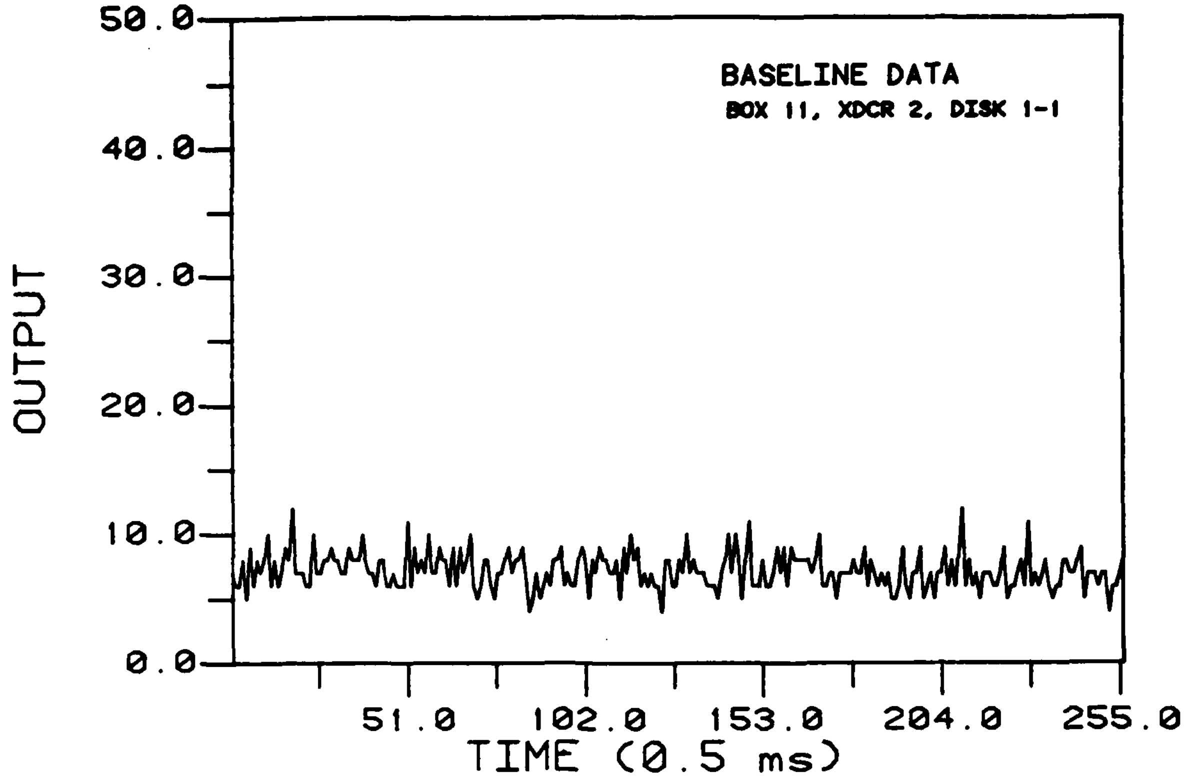
15-25 MICRON G
BOX 10, XDCR 3, DISK 9-1
-- FREQUENCY
— ACCUMULATION
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT

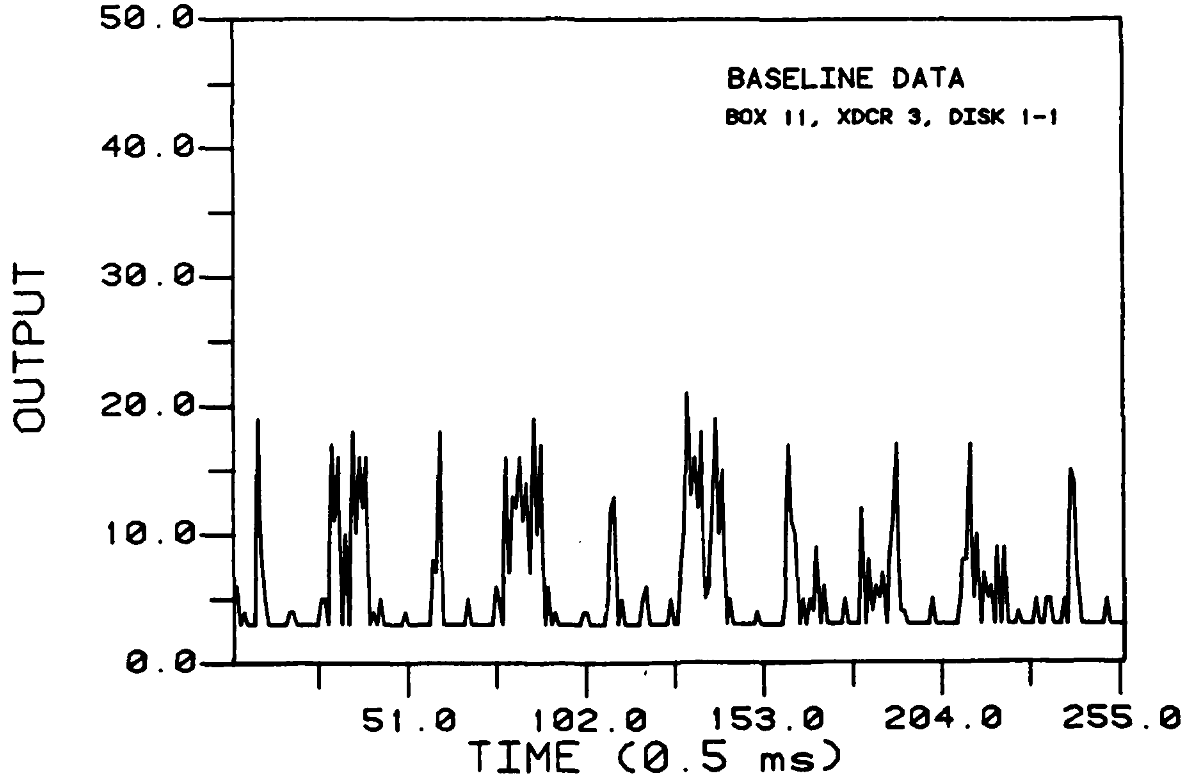


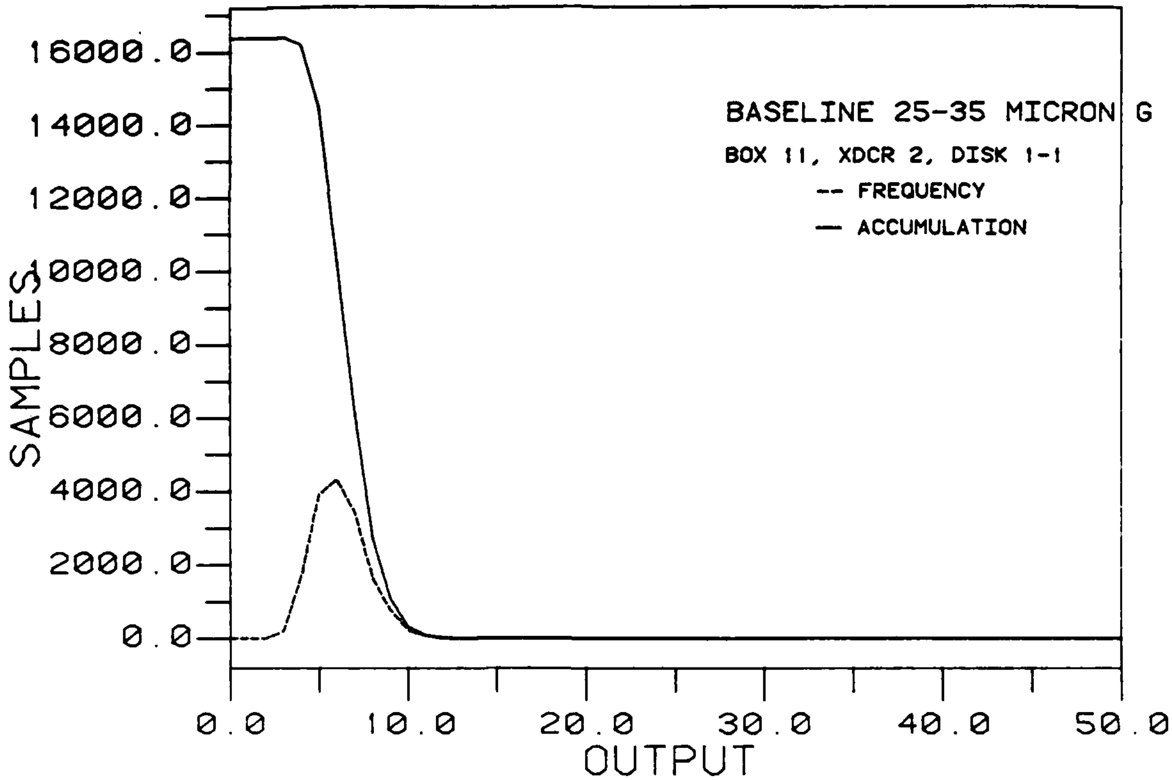
15-25 MICRON G
BOX 10, XDCR 2, DISK 9-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

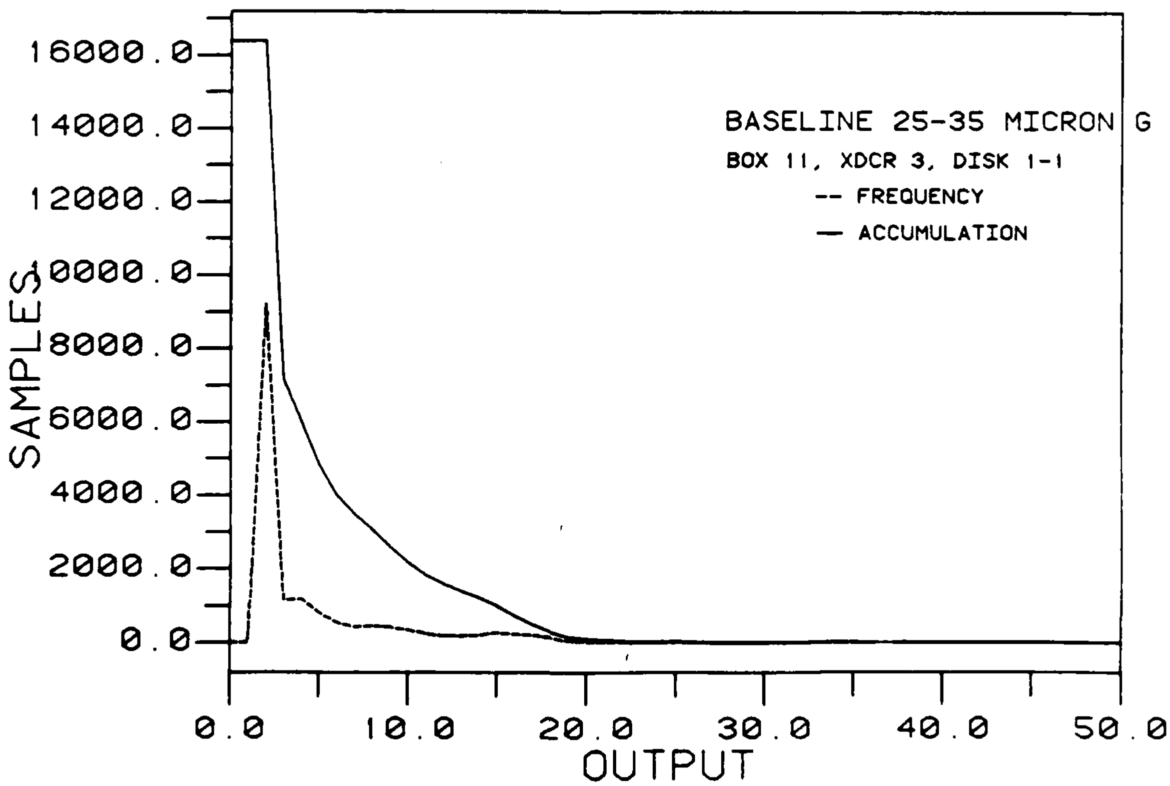


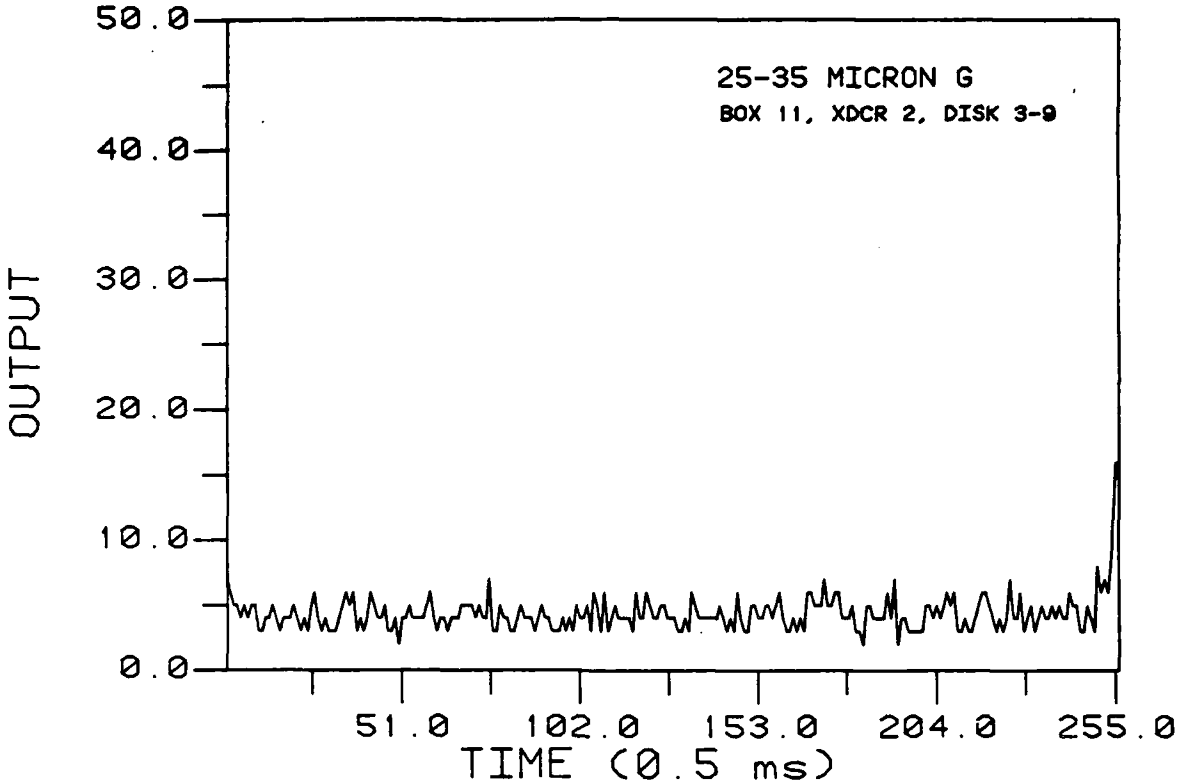
15-25 MICRON G
BOX 10, XDCR 3, DISK 9-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


BASELINE DATA
BOX 11, XDCR 2, DISK 1-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


BASELINE DATA
BOX 11, XDCR 3, DISK 1-1
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


BASELINE 25-35 MICRON G
BOX 11, XDCR 2, DISK 1-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
OUTPUT
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
10.0
20.0
30.0
40.0
50.0


BASELINE 25-35 MICRON G
BOX 11, XDCR 3, DISK 1-1
-- FREQUENCY
— ACCUMULATION
SAMPLES
OUTPUT
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
10.0
20.0
30.0
40.0
50.0



25-35 MICRON G
BOX 11, XDCR 2, DISK 3-9
OUTPUT
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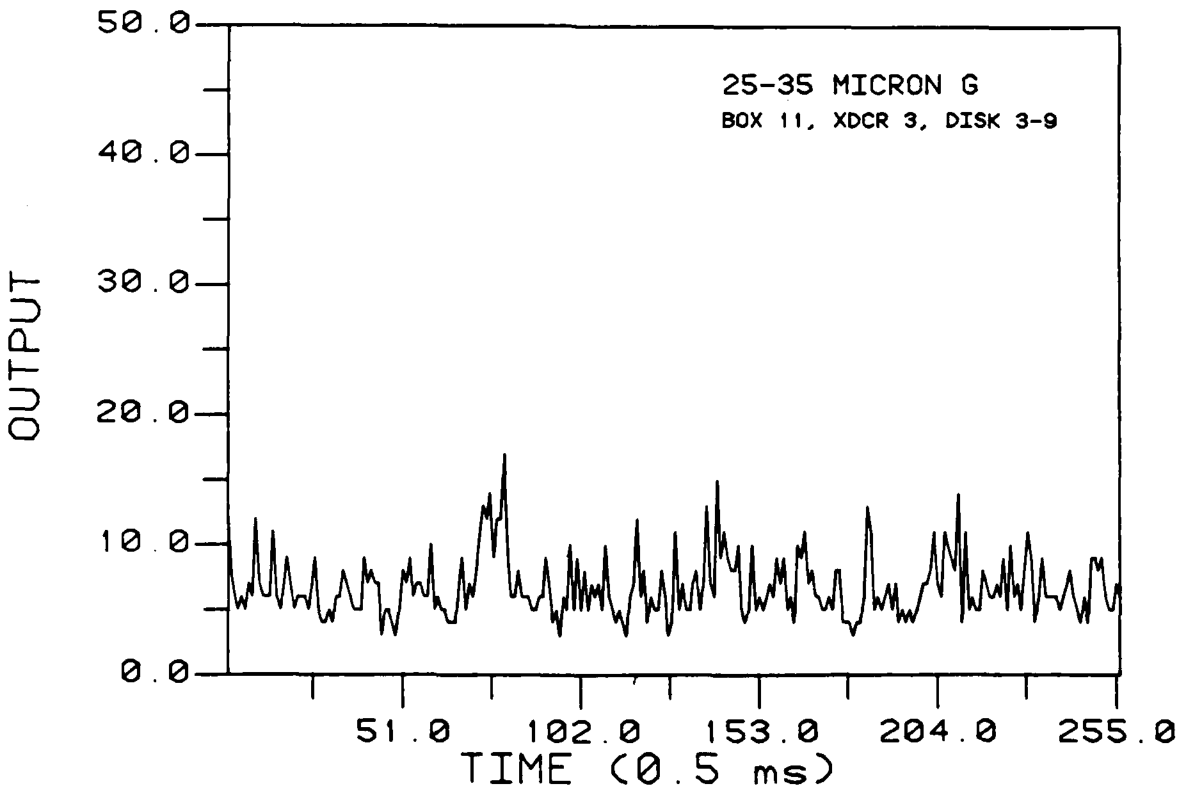
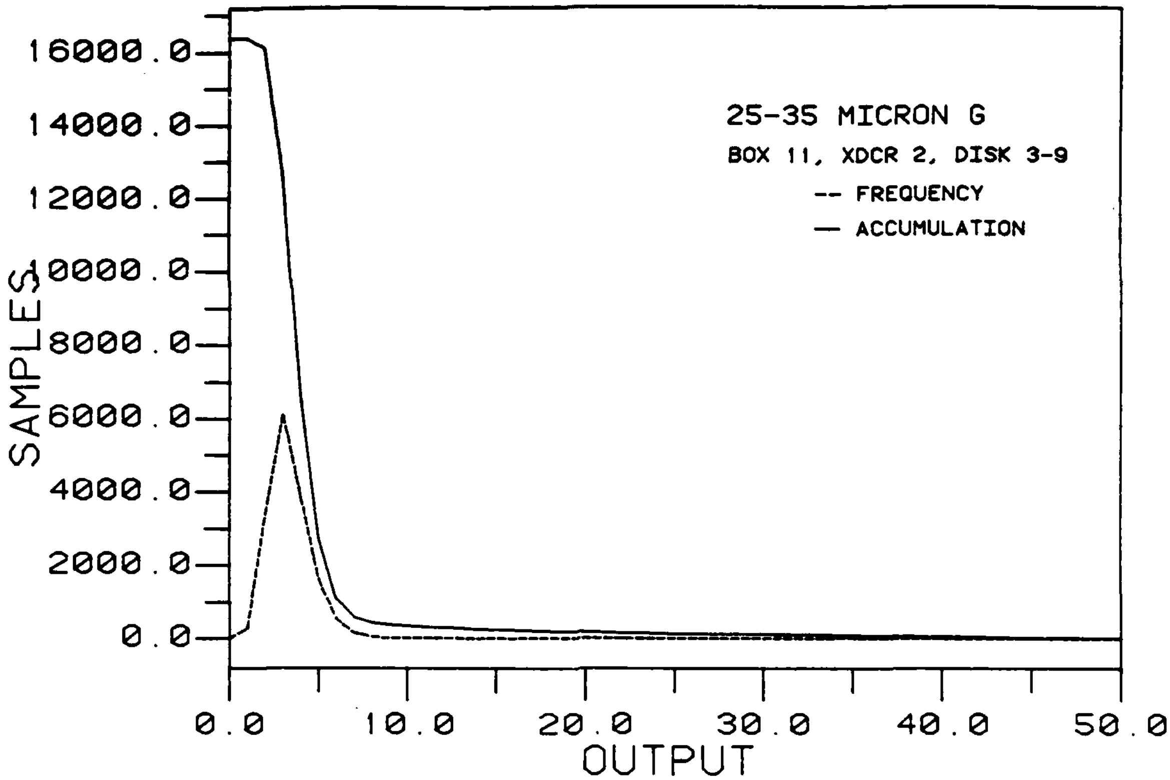
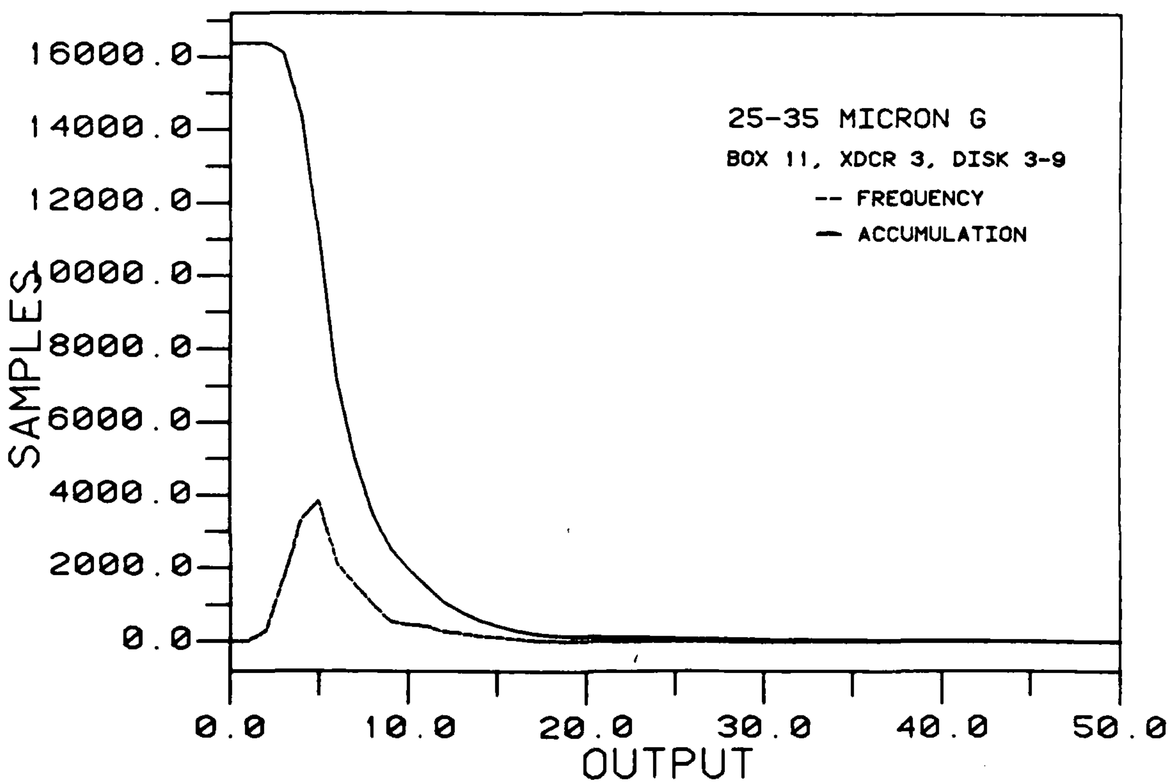
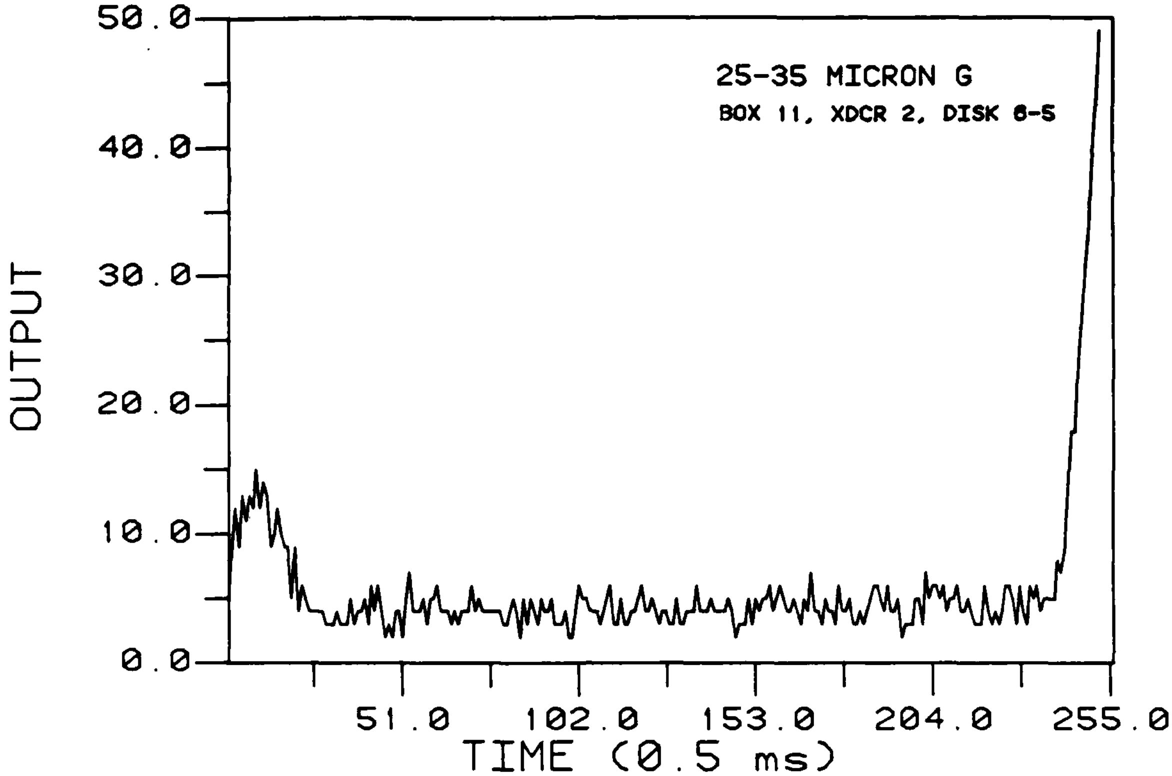
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



25-35 MICRON G
BOX 11, XDCR 3, DISK 3-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
25-35 MICRON G
BOX 11, XDCR 2, DISK 3-9
-- FREQUENCY
— ACCUMULATION


16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
25-35 MICRON G
BOX 11, XDCR 3, DISK 3-9
-- FREQUENCY
— ACCUMULATION


25-35 MICRON G
BOX 11, XDCR 2, DISK 6-5
OUTPUT
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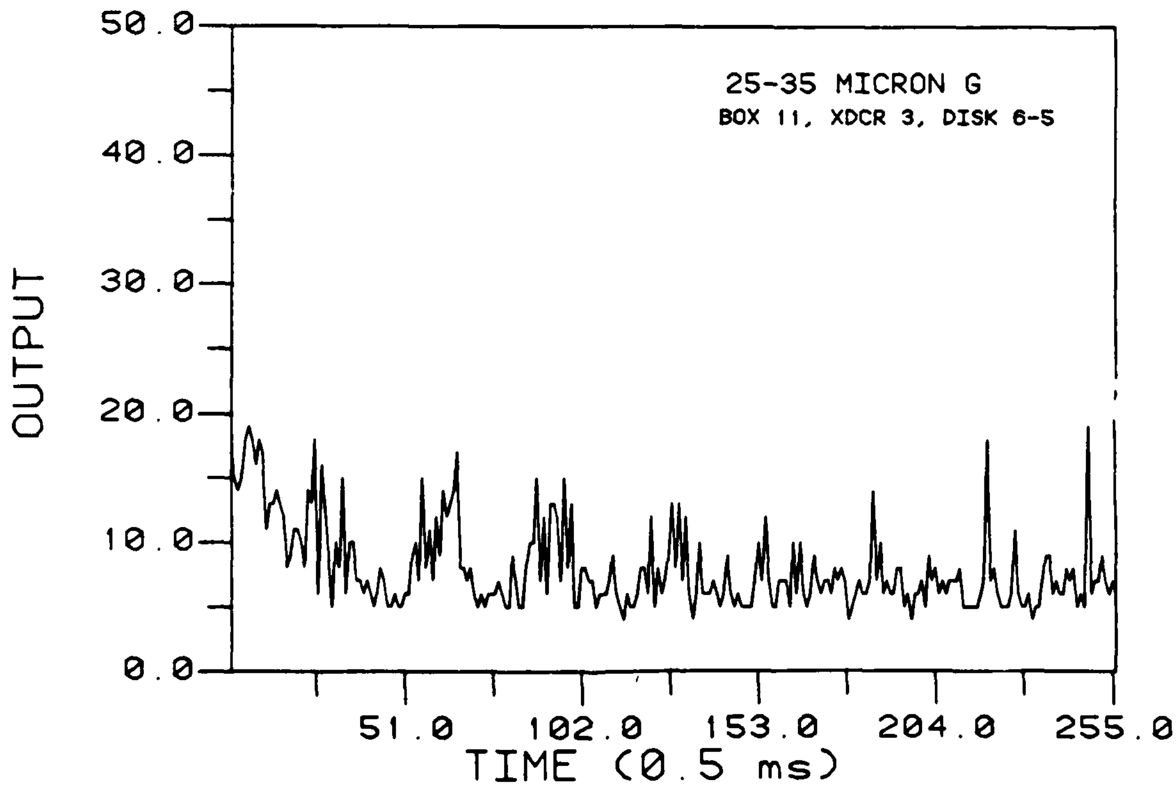
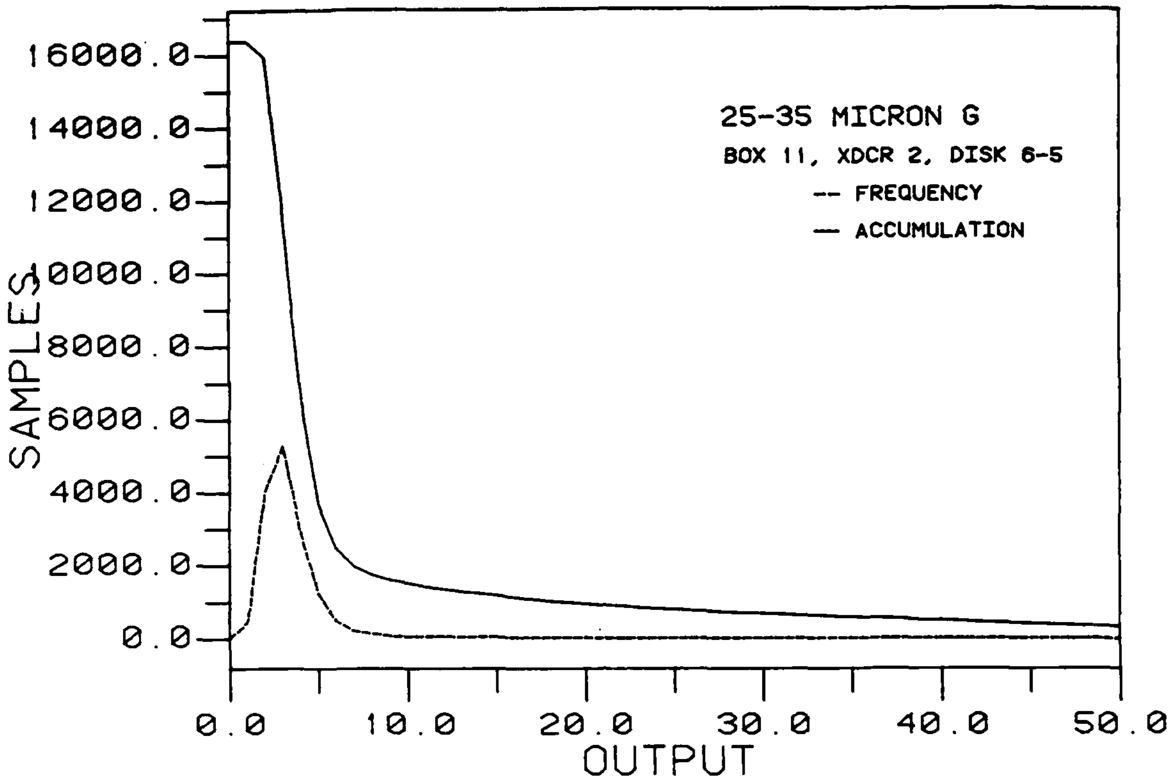
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


25-35 MICRON G
BOX 11, XDCR 3, DISK 6-5
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


25-35 MICRON G
BOX 11, XDCR 2, DISK 6-5
-- FREQUENCY
— ACCUMULATION
SAMPLES
OUTPUT
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14000.0
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10000.0
8000.0
6000.0
4000.0
2000.0
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10.0
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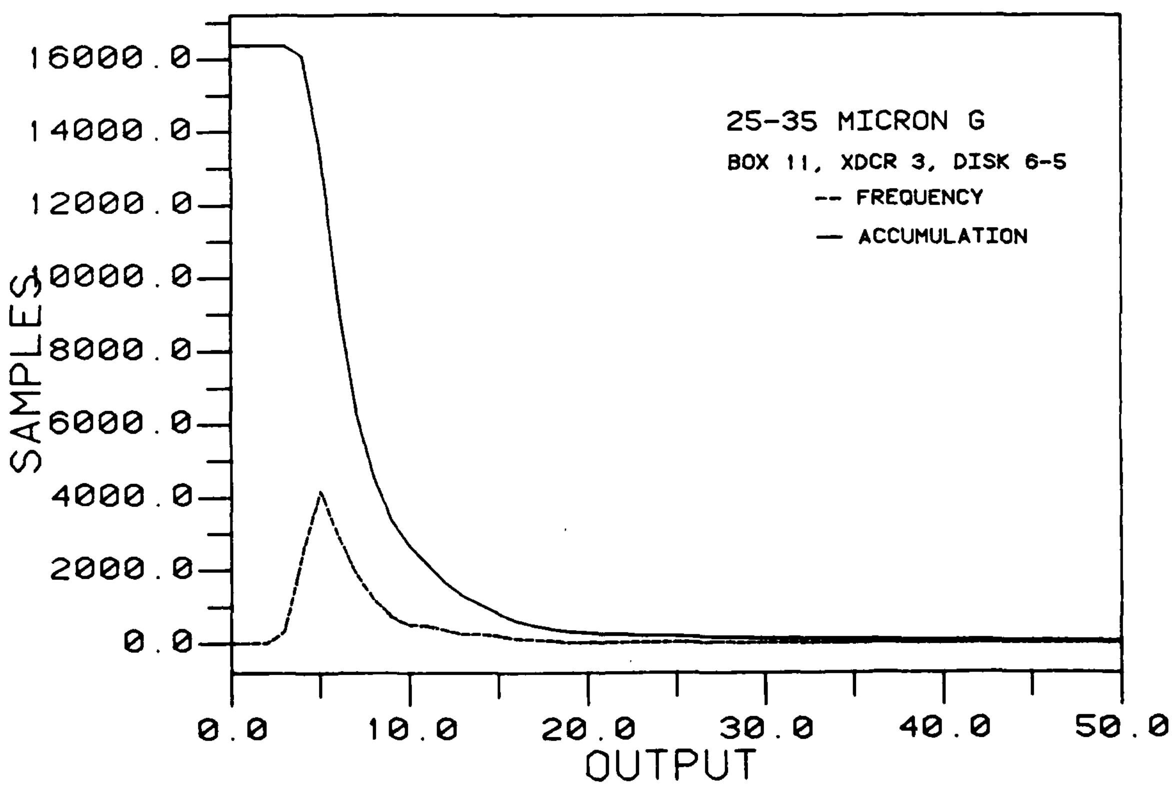
50.0


25-35 MICRON G
BOX 11, XDCR 3, DISK 6-5
-- FREQUENCY
— ACCUMULATION
SAMPLES
OUTPUT
16000.0
14000.0
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10000.0
8000.0
6000.0
4000.0
2000.0
0.0
10.0
20.0
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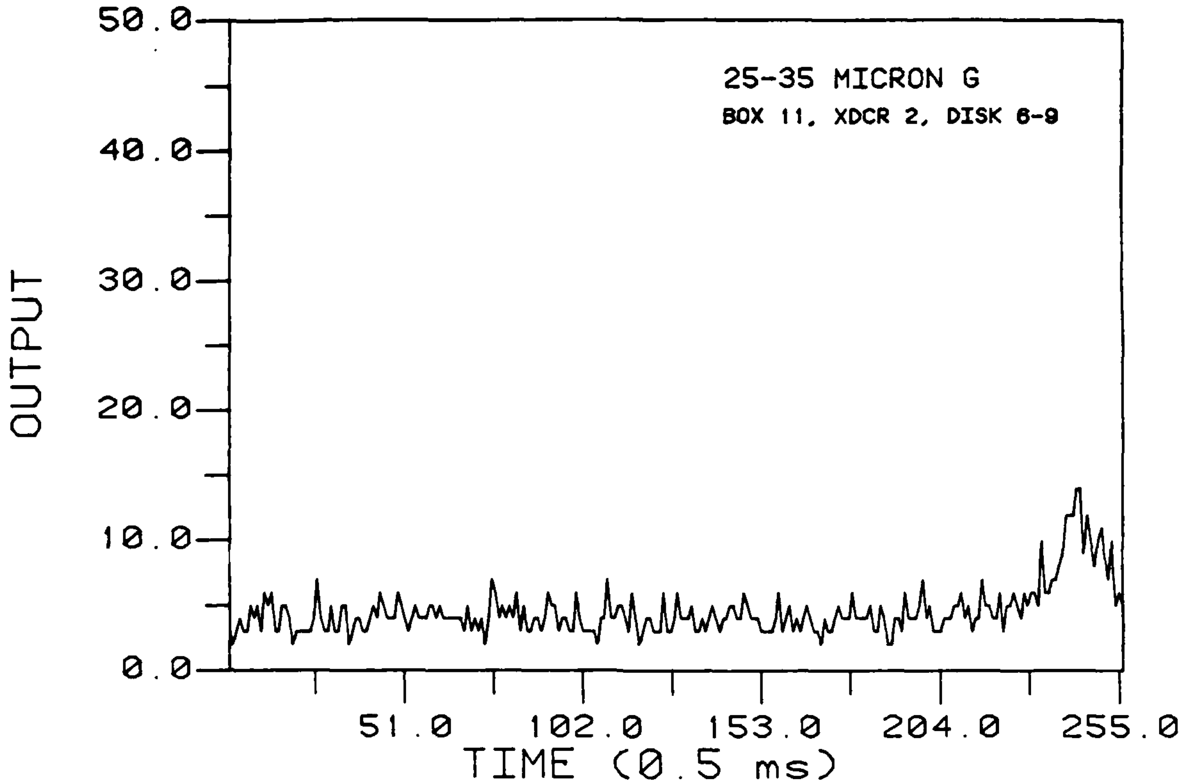
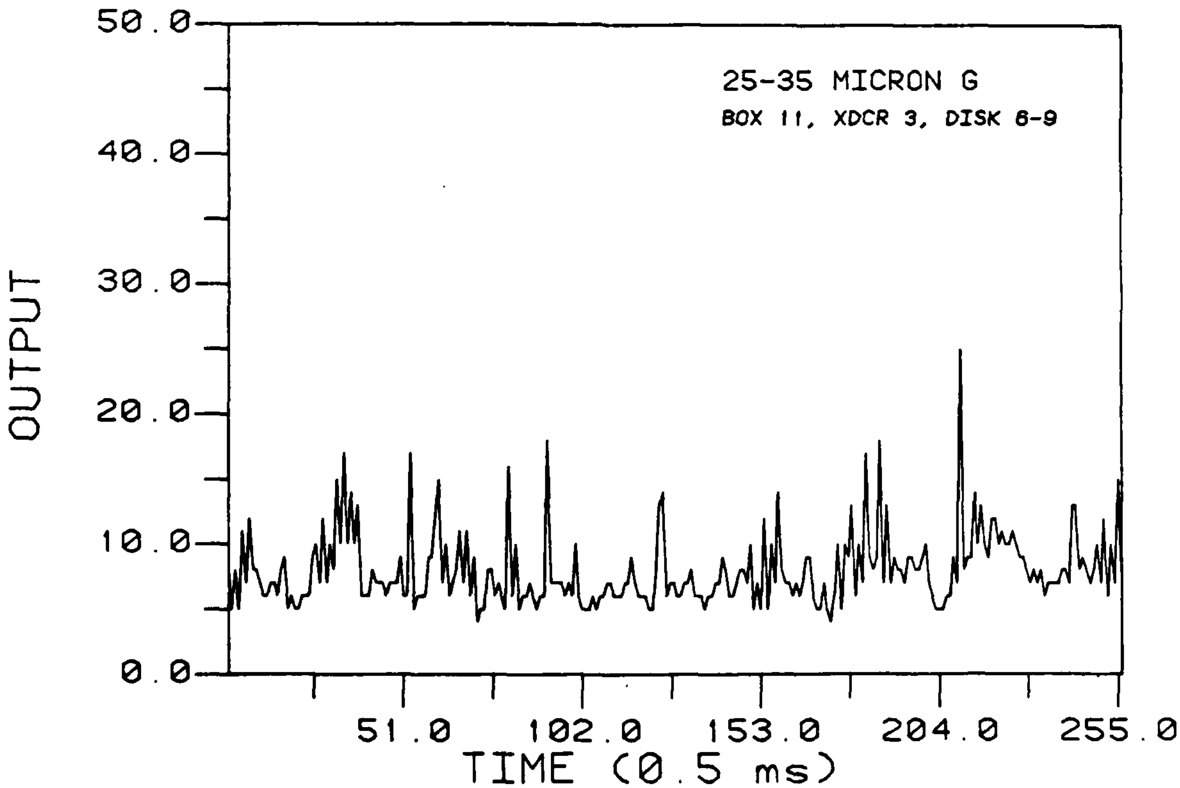
40.0
50.0


25-35 MICRON G
BOX 11, XDCR 2, DISK 6-9
OUTPUT
50.0
40.0
30.0
20.0
10.0
0.0
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


25-35 MICRON G
BOX 11, XDCR 3, DISK 6-9
OUTPUT
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20.0
10.0
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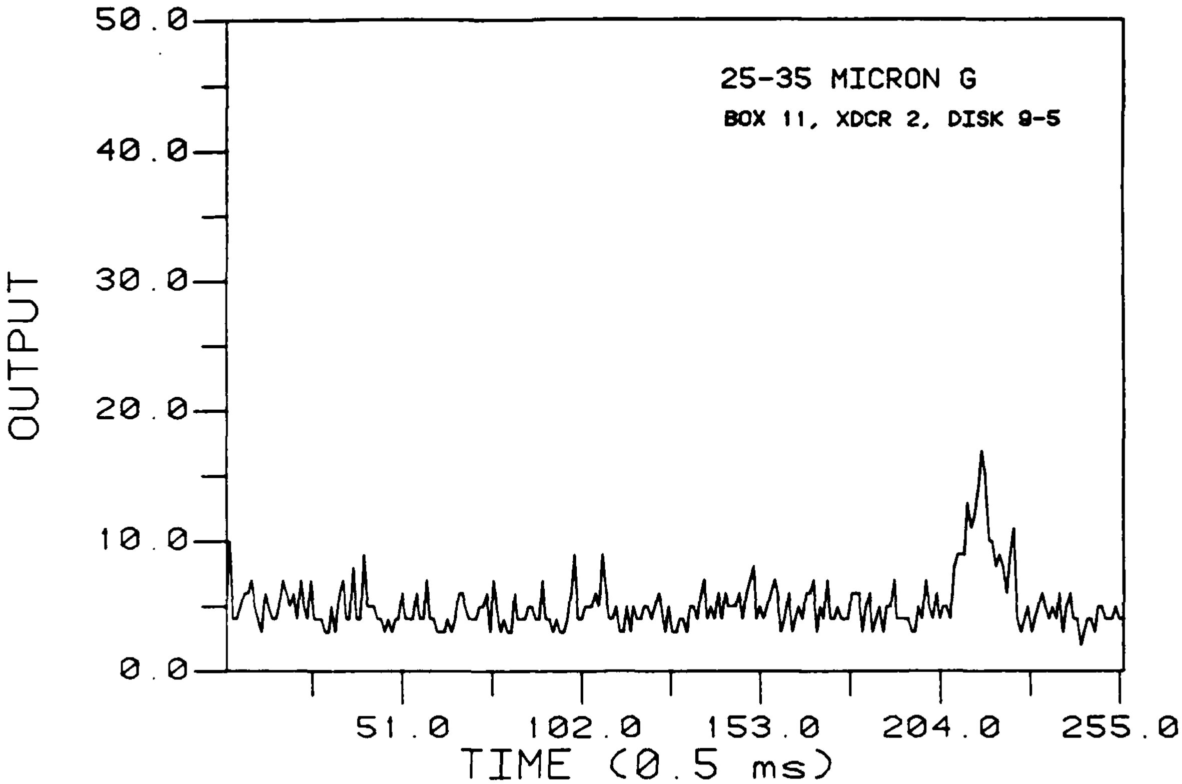
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


25-35 MICRON G
BOX 11, XDCR 2, DISK 9-5
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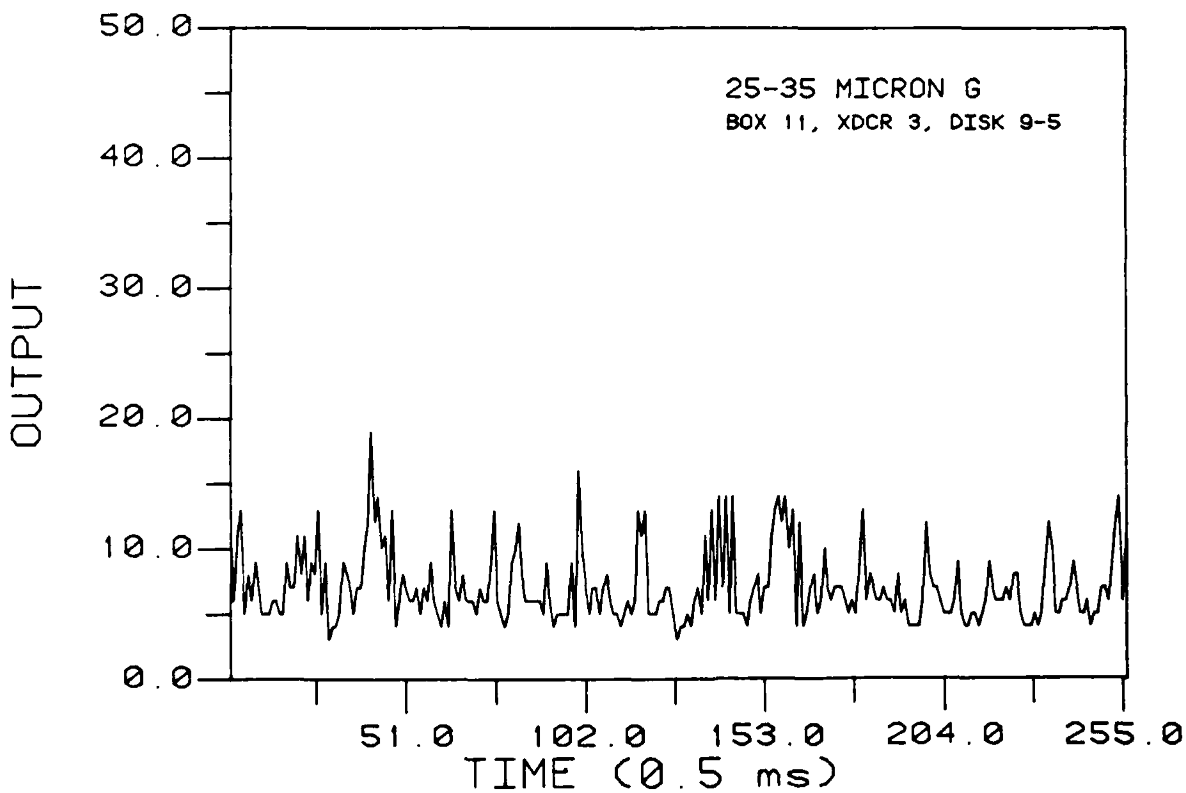
20.0
10.0
0.0
OUTPUT
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)


25-35 MICRON G
BOX 11, XDCR 3, DISK 9-5
50.0
40.0
30.0
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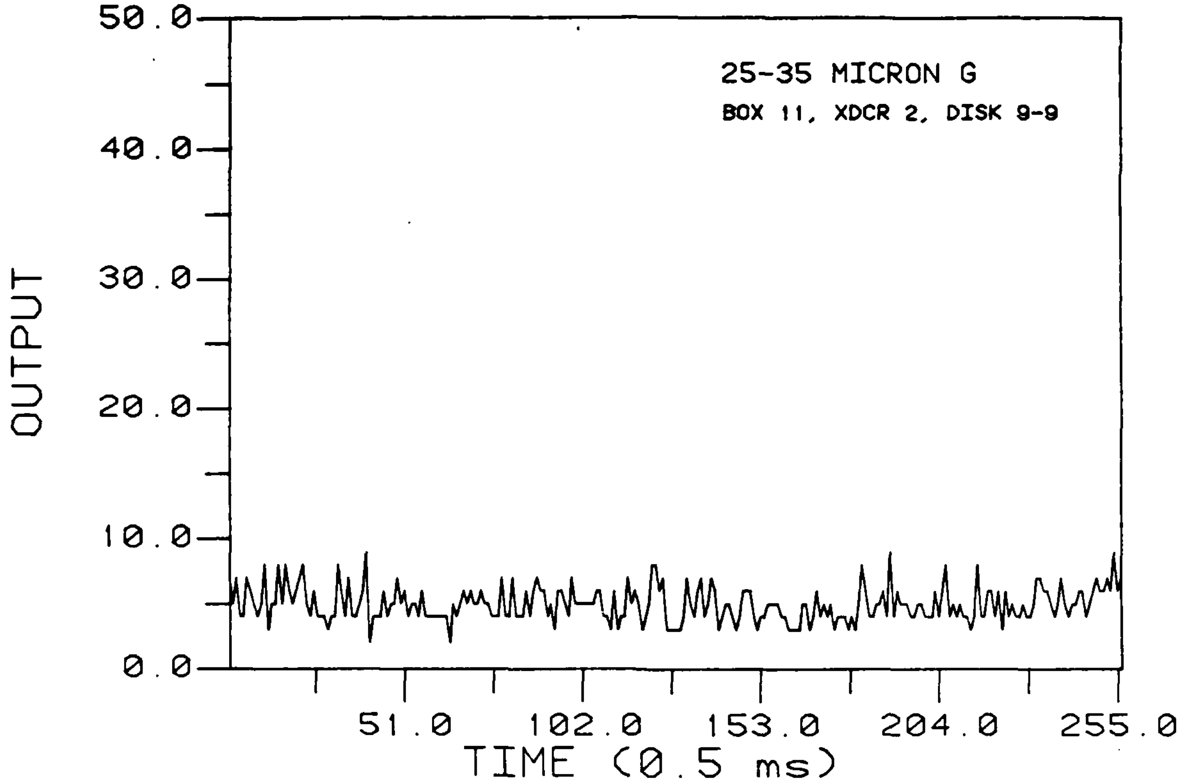
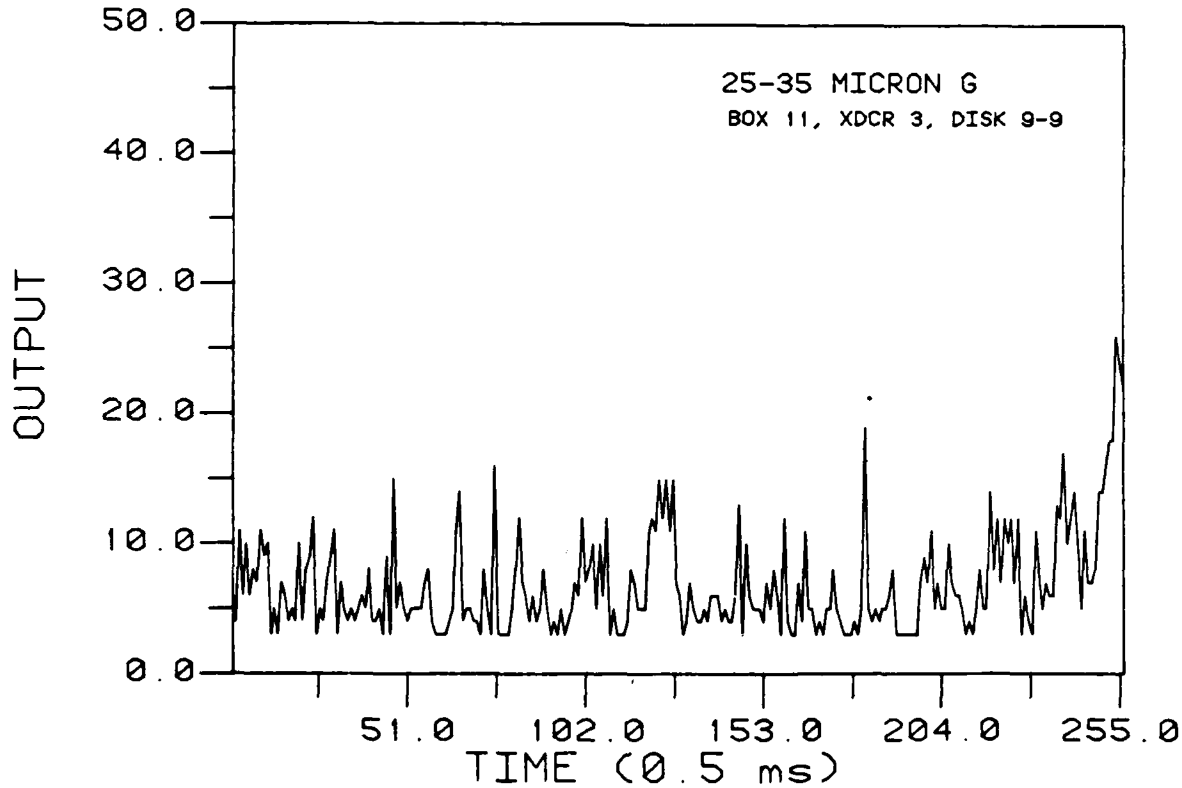
10.0
0.0
OUTPUT
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



25-35 MICRON G
BOX 11, XDCR 2, DISK 9-9
50.0
40.0
30.0
20.0
10.0
0.0
OUTPUT
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)



25-35 MICRON G
BOX 11, XDCR 3, DISK 9-9
50.0
40.0
30.0
20.0
10.0
0.0
OUTPUT
51.0
102.0
153.0
204.0
255.0
TIME (0.5 ms)

PEAK DETECTOR: MD 702A

a. Delay: 2-40 microsec, adjust to 22*

b. Gate: 0.1-2 microsec, adjust to 2*

c. Gate Mode: Delayed Gate

d. Sync Mode: Trig

e. Polarity: +

f. Out Mode: Linear

* Assumes sound velocity in the medium is 1100 m/s.

OSCILLOSCOPE:

Because of the variations among scopes, only generalities will be discussed.

Amplifier: A 50 Ohm terminator is recommended for accurate input voltage measurements.

a. Volt/Div: .5

b. Display Mode: Alternate

Turn on the following equipment:

a. R-105 Amplifier's Power Supply (+15 VDC)

b. TM-506 Power Supply

c. Oscilloscope

2. DATA ACQUISITION:

WARNING: Review APPENDIX D1 FLUID MODEL OPERATIONAL PROCEDURES. Ensure the valve alignment is as shown in Figure D1 and electonics equipment setup as discussed above.

a. Set PUMP CONTROL to 10 and start pump.

b. Seed the control volume per SEEDING THE CONTROL VOLUME WITH TEST PARTICLES.

DATA ACQUISITION OPERATION PROCEDURES

In this procedure statements preceded by the following words are of special significance:

****

WARNING: Means that there is possibility of personal injury to yourself or others.

CAUTION: Means that there is the possibility of damage to the model or other related components.

NOTE: Indicates points of particular interest for more efficient and convenient operation.

****

1. START ELECTRONICS:

CAUTION: Ensure cables are connected per Figure D2 before turning on power.

Initial Instrumentation Settings:

PULSER: MP 215

a.	Rep Rate:	Adjust to 2 KHz
b.	Trigger:	Internal
c.	Pulse Amplitude:	Rotate fully Clockwise (CW)
d.	Damping:	Rotate fully CCW (on detent)
e.	Pulse Width:	High

RECEIVER-AMPLIFIER: MR 106

a.	Filter:	1 MHz
b.	Gain:	As necessary
c.	Detector:	Off

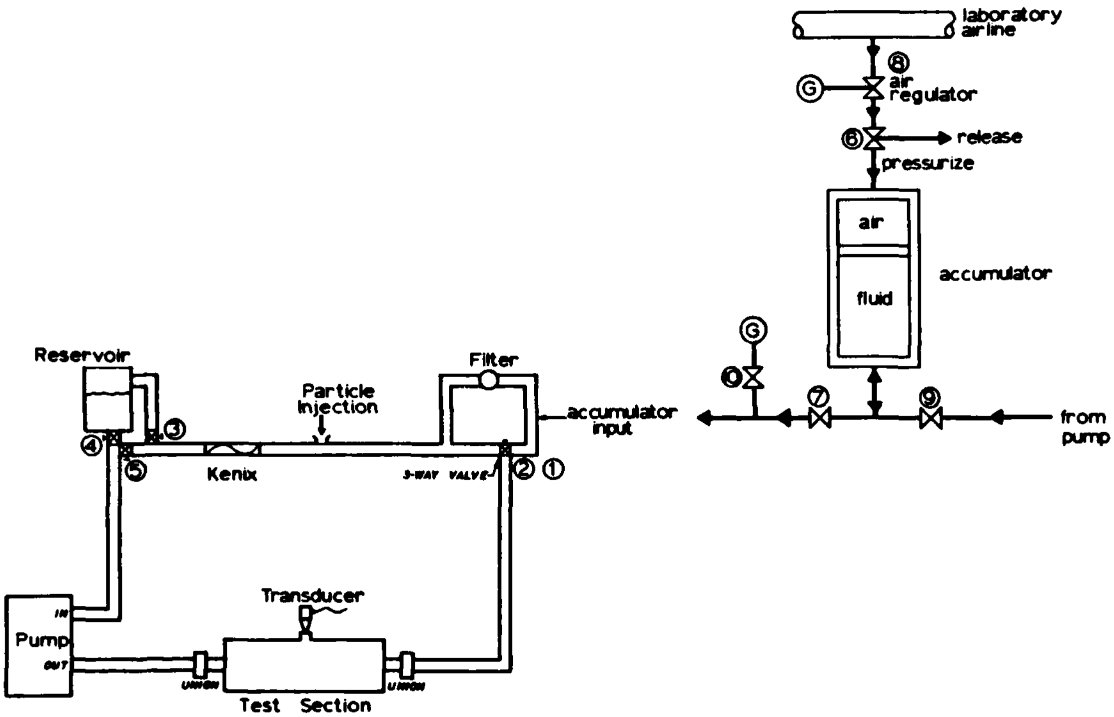


FIGURE D1 FLUID MODEL VALVE ALIGNMENT

TABLE D1 FLUID MODEL VALVE ALIGNMENT

VALVE	POSITION	DESCRIPTION
1	CLOSED	VENT
2	DOWN(to system)	THREE-WAY
3	CLOSED	RESERVOIR In
4	CLOSED	RESERVOIR Out
5	OPEN	BYPASS
6	RELEASE	Loop PRESSURIZATION
7	OPEN	ACCUMULATOR Out
8	0 PSIG	Air REGULATOR
9	CLOSED	ACCUMULATOR FILL
10	OPEN	GAGE

iv. Mix the particles and fluid thoroughly.

NOTE: Using a stirring bar and stirrer plate (Corning) does not ensure the particles are in suspension or entirely dispersed throughout the test fluid.

a. Draw fluid and particles slowly into a 1cc syringe.

b. Invert the syringe and allow air bubbles to escape. The plunger may require being drawn out further to let the air pass.

c. Set the plunger to the 1cc mark.

d. Remove the grey (plugged) syringe and allow fluid to gently flow up the needle's neck. Attach the syringe quickly to prevent fluid loss.

e. Adjust the lab air REGULATOR valve (8) to 30 PSIG.

f. Pressurize the loop by rotating the loop PRESSURIZATION valve (6) clockwise 180°.

g. Operate the pump moderately with PUMP CONTROL setting at 15-20.

h. Depress the plunger very slowly to allow an even distribution along the fluid flow. Once fully depressed, allow the system pressure to refill the syringe. Continue this step several times to remove all particles from inside the syringe.

WARNING: The syringe plunger may blow out if not careful.

i. Stop the pump.

j. Release system pressure by rotating the loop PRESSURIZATION valve (6) counterclockwise 180°.

k. Remove and replace the syringe with the grey plugged syringe.

l. Repressurize the system by rotating the loop PRESSURIZATION valve (6) clockwise.

m. Start the pump by setting the PUMP CONTROL to 20 and allow circulation for 5-10 minutes before data acquisition.

6. **SEEDING THE CONTROL VOLUME WITH TEST PARTICLES:**

CAUTION: Ensure the valve alignment is as Figure D1.

NOTE: For each test run, with increasing particle diameter, the particles per injection remains the same. Also, the maximum particle diameter depends directly on the fluid's viscosity to hold them in semi-suspension. Steps (i) thru (iv) are in preparation for seeding the control volume.

i. Weigh out approximately 15 g of test fluid in a 25ml flask.

ii. Begin the test program with the smallest particles. For particles less than 50 micron diameter, a good rule of thumb for calculating W_{P1} is using:

$$W_{P1} = 0.01\%\ W_f/0.01$$

$$W_{P2} = W_{P1}\{\frac{D2}{D1}\}^3\{\frac{\rho_2}{\rho_1}\}$$

$$P_{inj} = \frac{6}{\pi}\ (W_{P1}\ \rho_f/(W_f\ \rho_1 D1^3)$$

where:

W_{P1} = Weight first particle in test, mg

W_{P2} = Weight follow-on particles, mg

W_f = Weight fluid, g

D1 = Diameter first particle, cm

D2 = Diameter follow-on particles, cm

P_{inj} = Number of particles per injection.

ρ_1 = Density first particle, g/cm^3

ρ_2 = Density follow-on particles, g/cm^3

ρ_f = Density fluid, g/cm^3

iii. Weigh out W_{P1} and combine with the test fluid.

5. CLEAN THE CONTROL VOLUME FLUID:

CAUTION: Ensure the valve alignment is as Figure D1.

a. Pressurize the loop by setting the air REGULATOR valve (8) to 40 PSIG.

b. Rotate THREE-WAY valve (2) to the up position for flow through the filter loop.

c. Operate pump at fast speed with the PUMP CONTROL setting to 60.

d. Rotate THREE-WAY valve (2) quickly between up and down positions to remove trapped particles in stagnant sections of the loop.

WARNING: DO NOT STOP the THREE-WAY valve (2) MID-POSITION for <u>any</u> length of time: Rupture to the piping is eminent.

NOTE: Before using the oscillioscope in the next paragraph, review APPENDIX D2 DATA ACQUISITION OPERATION PROCEDURES.

Allow circulation for a minimum of 30-60 minutes if the system has not been operated for several days. To verify the system cleanliness, reduce the PUMP CONTROL setting to 10 and observe the oscilloscope for particle reflections about the gated region. If reflections exist, then increase the PUMP CONTROL back to 60 and continue cleaning. If there are no reflections:

a. Rotate the THREE-WAY valve (2) to the down position and observe the oscilloscope for reflections. Set the PUMP CONTROL at 10. If reflections exist, go back to step 5a. If no reflections, then the cleaning operation is complete.

NOTE: Particles may be settled to the bottom of the dead section of piping in the control volume loop and stirred up only after the flow shift is made. Therefore, it is important to make these observations frequently during cleaning.

The loop pressure gage should begin to rise immediately and reach within 10 PSIG of the regulator's pressure gage.

c. Adjust lab air REGULATOR valve (8) to 40 PSIG.

NOTE: If the loop pressure gage fails to rise accordingly or drops during operation, it is usually the indication of an empty accumulator. The accumulator's capacity is about 500ml.

3. ACCUMULATOR FILLING:

a. Reduce loop system pressure then put valve alignment per Figure D1.

b. Close ACCUMULATOR OUT valve (7).

c. Open ACCUMULATOR FILL valve (9).

d. Ensure adequate supply fluid is available to the peristaltic pump's suction.

e. Place the accumulator air discharge tubing into a beaker of water. As air is forced out of the accumulator during filling, it will provide tell-tale air bubbles until the accumulator's (oil side) is full.

d. Start the peristaltic pump. The pump may be set at a high speed for this operation. Secure the pump when the tell-tale air bubbles cease.

e. Put the valve alignment per Figure D1.

4. PROPER PUMP OPERATION:

CAUTION: Do not operate the pump in reverse for two reasons:

i. Contaminated oil will flow into the clean side of the filter loop.

ii. The pump's rotor will unscrew and detach. This necesitates removal and disassembly of the pump to reengage the rotor.

j. Repeat step c. with PUMP CONTROL set to 20.

k. Continously rotate the THREE-WAY valve (2) slowly between mid-position and down for several cycles. Any air in the corners should be forced out.

WARNING: DO NOT STOP the THREE-WAY valve (2) MID-POSITION for <u>any</u> length of time: Rupture to the piping may occur.

l. Stop the pump.

m. Rotate the THREE-WAY valve (2) between down and up several times to bring trapped air to the vent leg.

n. Crack open VENT valve (1) to discharge the air.

o. Reset valve alignment as to Figure D1.

<u>MINOR FILL:</u> Use the PERISTALTIC PUMP.

a. Open ACCUMULATOR FILL valve (9) and start pump. Ensure pump has an adequate oil supply and adjust speed to the high side.

b. Crack open VENT valve (1) to allow air to escape and close when filter loop is full.

c. Follow procedures in the preceeding paragraph as applicable.

d. Stop pump when filled and Repeat step 1.o.

Most of the air should be gone, however, further use of the system should trap the remainder. Using steps l. thru n. can help remove that.

2. SYSTEM PRESSURIZATION:

CAUTION: Ensure the valve alignment is as Figure D1.

a. Set lab air REGULATOR valve (8) to 30 PSIG.

b. Rotate loop PRESSURIZATION valve (6) clockwise to pressurize the entire system. (The valve handle should be pointing to your left.)

FLUID MODEL OPERATIONAL PROCEDURES

In this procedure statements preceded by the following words are of special significance:

****

WARNING: Means that there is possibility of personal injury to yourself or others.

CAUTION: Means that there is the possibility of damage to the model or other related components.

NOTE: Indicates points of particular interest for more efficient and convenient operation.

****

1. FILL MODEL:

CAUTION: Ensure the valve alignment is as Figure D1.

MAJOR FILL: Fill and use the RESERVOIR.

a. Close BYPASS valve (5).

b. Open RESERVOIR valves (3) and (4).

CAUTION: Review the section on PROPER PUMP OPERATION before continuing.

c. Operate the pump slowly with the PUMP CONTROL setting of 10 or less to circulate the fluid.

d. Crack open VENT valve (1) to fill the filter loop. Shut after the vent leg has filled.

e. Stop the pump.

f. Once the control volume is filled, rotate the THREE-WAY valve (2) to the up position to continue filling the filter loop.

g. Repeat step d.

h. Slowly remove the vent PLUG on top of the filter housing and bleed air out. Replace plug when fluid appears.

i. Rotate THREE-WAY valve (2) to the down position.

APPENDIX D

OPERATIONAL PROCEDURES

1. FLUID MODEL
2. DATA ACQUISITION

40 KHz, however, the overall instrument is capable of 10 KHz. Once a value is digitized, it is held until fetched by the computer.

Transducers: Transducers were procurred from three companies:

Harisonic Labs	Stamford, Cn
Panametrics	Waltham, Ma
Ultran Labs	State College, Pa

Of the three, Harisonic Labs provided the lowest cost and quickest delivery. They were open to new designs with prompt replies to any such questions.

Both Harisonic Labs and Panametrics provided the most sensitive transducers for this application.

Both Harisonic Labs and Ultran will consider building high temperature probes.

All companies are a pleasure to work with.

LIST OF EQUIPMENT

1. FLUID SYSTEM MODEL

Pump:	Ramoy Model 341
Filter Housing:	Facet
Filter Cartridge:	Pleated 20 inch 0.45 micron
Piping:	Schedule 40 Clear PVC
Fluid:	Dow Corning 200 (200 CSt)

2. DATA ACQUISITION

Transducers:	see below
Power Supply:	Tektronix TM 506
Pulser:	MetroTek MP-215
Receiver-Amplifier:	MetroTek R-105 MetroTek MR-106
Peak Detector:	MetroTek MD-702A
Computer:	Digital MINC-11 (PDP-11)

3. PARTICLES:

Particle Information Service
Washington State

Notes:

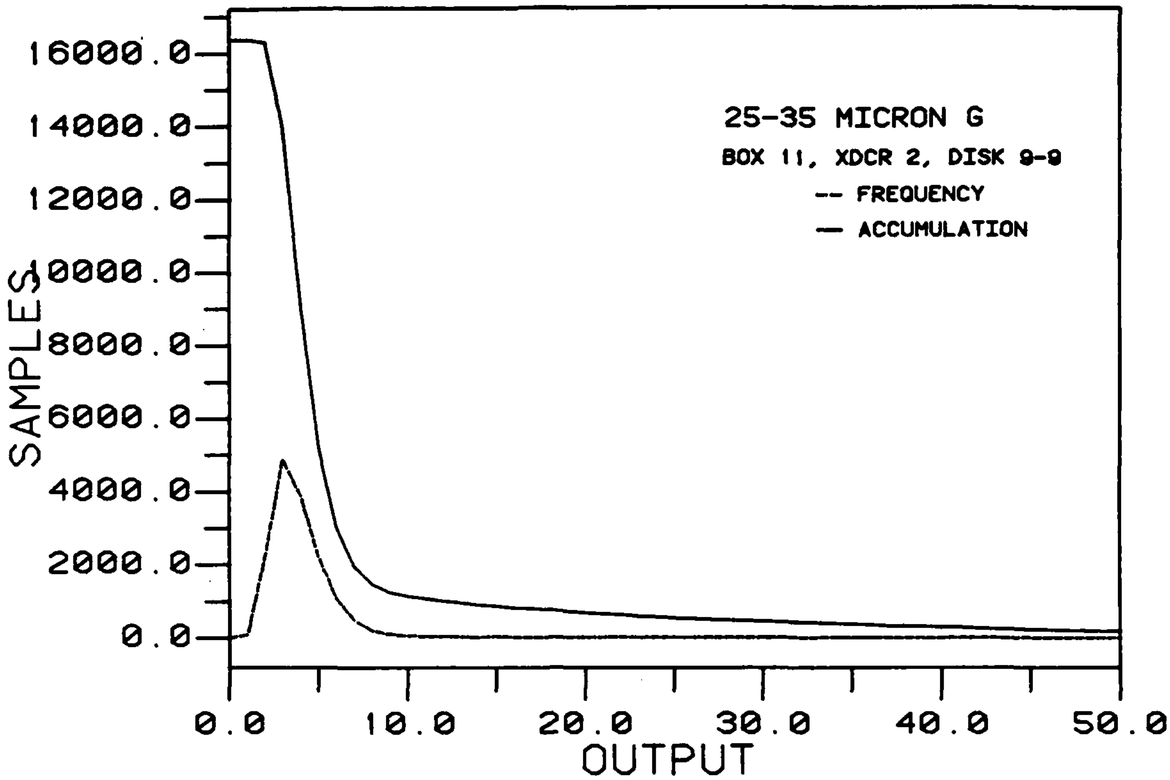
Peak Detectors: Input 0 - 2 Volts; Output 0 - 10 Volts

The MetroTek MD-702 is unique because each pulse provides a new data point. Most pulsers on the market require several inputs before a output is ready. Although this makes little difference in a hand held flaw detector, to hold the transducer in place for another second, it can make a difference in the quality and speed of data acquisition for this particular application.

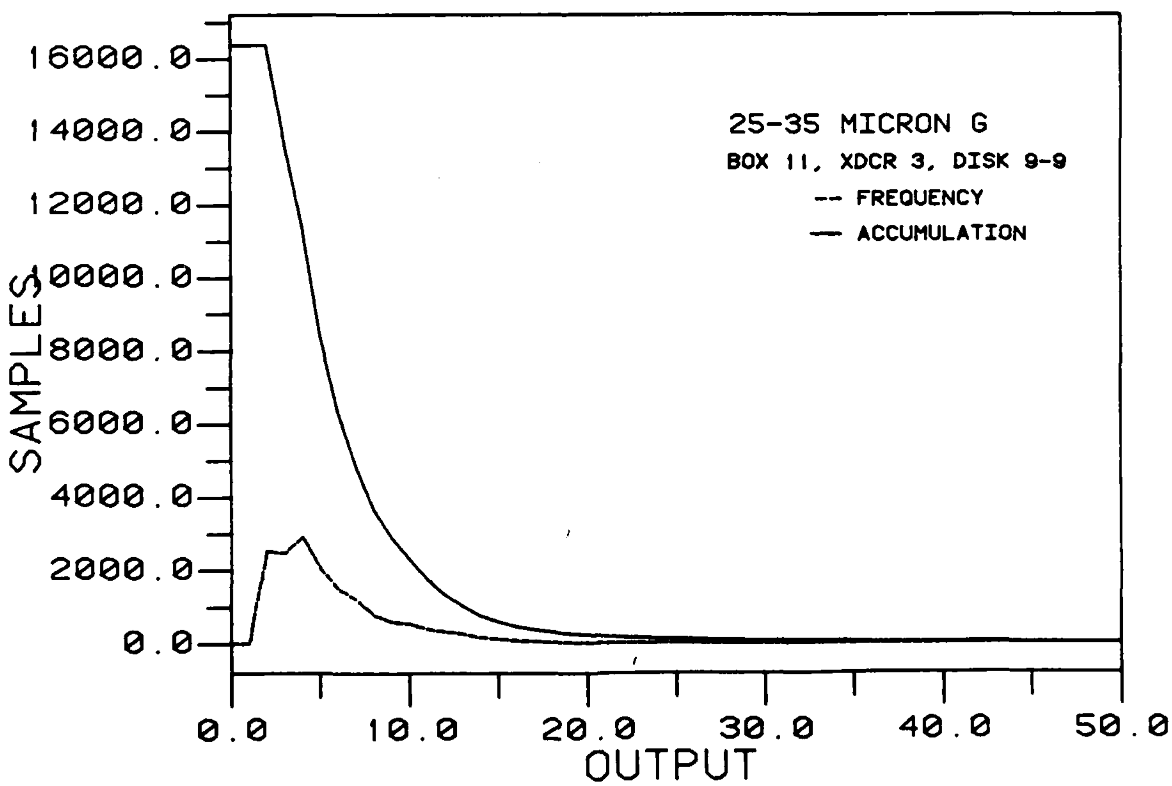
Another feature is Option A which digitizes the largest peak within the gated region. The speed of this digitizer is at

APPENDIX C

LIST OF EQUIPMENT



16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
25-35 MICRON G
BOX 11, XDCR 2, DISK 9-9
-- FREQUENCY
— ACCUMULATION



16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
SAMPLES
0.0
10.0
20.0
30.0
40.0
50.0
OUTPUT
25-35 MICRON G
BOX 11, XDCR 3, DISK 9-9
-- FREQUENCY
— ACCUMULATION

COMPUTER PRELIMINARIES:

c. Place the "TWO TRANSDUCER" System disk in the left hand drive.

d. Place a new or empty disk in the right hand drive;

TYPE: @SY:FI

This will erase all previous information on the disk, format and initialize for data acquisition.

NOTE: If there are any BADBLOCKS found during the initializaition, use another disk.

e. To begin the data acquisition.

TYPE: .R DI2

Some preliminary questions then follow:

Do You Want The Bell To
Ring During Sampling? (Y or N) :

It is recommended the bell be allowed to ring for the first set of data to ensure a proper hookup between the TM 506 and the DEC MINC-11 computer.

TYPE: Y (no carriage return necessary)

Do You Want Continous
Sampling? (Y or N) :

Continous sampling fills the computer's internal memory and then rewrites over it with new data until commanded to stop. This is intended for future use with the extruder when the sampling time is not exact.

TYPE: N (no carriage return necessary)

Hold On .... Taking Samples

If a Y had been typed to have continous sampling, then the following would have occured:

Type G When Ready

Only a capital G will stop the data acquisition. The data collected will be for the time before the G was typed. The time for data collection is:

Number of Samples/Rep Rate(of the Pulser) = time (seconds)

Once acquisition has completed:

Do You Want To Save
This Set Of Data? (Y or N) :

If the data is <u>not</u> desired then:

TYPE: N (otherwise Y)

The DI2 program will start at the beginning again with the same preliminary questions. To answer Y, the data stored in internal memory is now written to flexible disk and then asks for a filename.

Enter New File Name *

TYPE: filename.DAT (and carriage return)

Once the above information is given, the program will start at the beginning again and ask the same preliminary questions.

NOTE: NINE FILES MAXIMUM per disk to allow further processing of the data. To plot the data, a minimum of 68 empty blocks are needed on the data disk.

3. PLOT DATA:

a. Place the "TWO TRANSDUCER" System disk in the left hand drive.

b. Place the data file disk in the right hand drive.

c. TYPE: @SY:PLOT

The following procedures should be used when:

This Program Changes The Bytes To Words
Input File Name ? :

*If the filename's extension is .DAT, then just type the filename without the extension.

*If the filename's extension is other than .DAT, the the data file must be renamed to have an extension of .DAT .

If an error occurs, the following will be shown:

Do You Want To Format Another File? (Y or N) :

If N is typed the program continues. If Y is typed the

program returns and asks for the correct filename.

Continuing on, two more programs are chained to this COMmon file. The next provides the frequency of occurance and displays this information in a Frequency Table and Accumulation Table by tapping the carriage return when requested. The data from both tables is written to disk for further viewing or analysis and is filed under:

ACUM1.DAT,	FRQ1.DAT
ACUM2.DAT,	FRQ2.DAT

The last program is a plotting algorithm (GENPLT). It is menu driven and does not need further explanation.

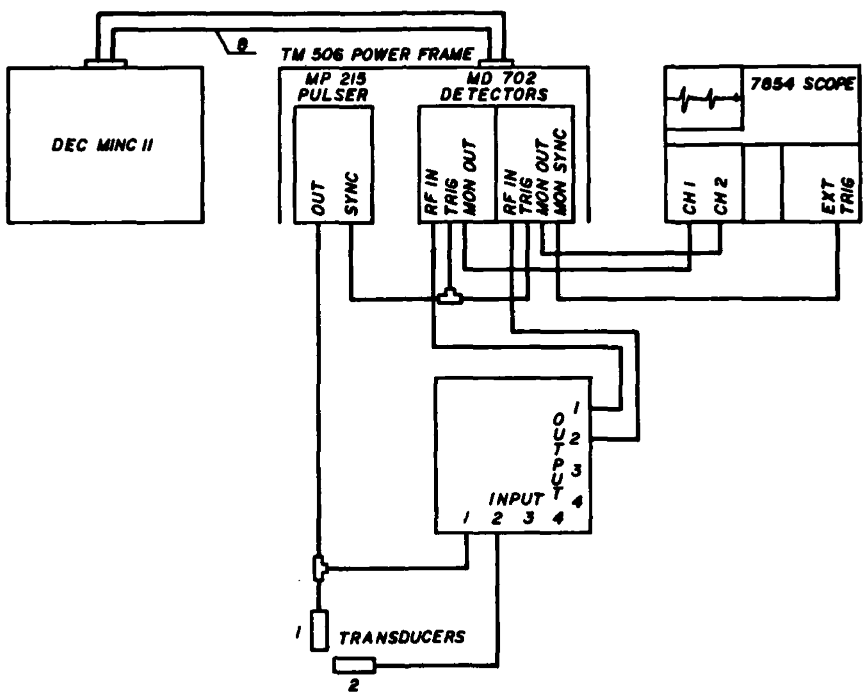


FIGURE D2 ELECTRONIC CABLE CONNECTIONS

END

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